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VOLUME XXXVIII NUMBER 1

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ROCK FLOORS IN ARID AND IN HUMID CLIMATES. I

W. M. DAVIS

ABSTRACT

This paper, after an introduction regarding the fundamental elements of the cycle of erosion, institutes a comparison between the barren mountain sides and the desert rock floors (pediments) of arid regions and the forested mountain slopes and the fertile peneplains of humid regions, with the object of discovering how far these contrasted landscapes are comparable with each other and of defining the various factors on which their contrasts depend. For humid regions the familiar principles of weathering and streams are followed; for arid regions the principles of degradation set forth by Lawson and the examples described by Bryan are accepted as guides. Sequences of forms are sketched for both regions, beginning with those which are largely consequent upon the deformation of a peneplain of massive granite, and ending with those which are wholly consequent upon the far advanced degradation of the deformed mass. It is concluded that a close analogy exists between the two sequences, and that their difference of appearance is due to their difference of climate. The plant cover of humid regions permits the accumulation of abundant soil even on fairly steep slopes; and of still deeper soil on lowlands of degradation; yet under the soil cover of mountain slopes boulders of decomposition are found grading into solid rock, which are closely homologous with the visible boulders resting on the bare rock of arid mountains. Similarly, under the heavy soil cover of a granite peneplain is a buried foundation of decomposed rock which is truly homologous with the gravel-veneered rock floors or pediments of arid degradation.

INTRODUCTION; THE CYCLE OF EROSION

The scheme of the cycle of erosion, now familiar to physiographers for nearly fifty years,[1] includes three essential principles. First, the forms produced by the action of erosional processes upon

[1] W. M. Davis, "Geographic Classification, Illustrated by a Study of Plains, Plateaus and Their Derivatives," *Proc. Amer. Assoc. Adv. Sci.*, Vol. XXXIII (1885), 428–32. It is here told that, as a body of horizontal strata emerges from its parental ocean, "a smooth, unbroken plain is revealed." As "effective elevation" is gained, "rivers establish their courses, the smooth plain is trenched. . . . . The channels

uplifted masses of earth crust vary with the nature of those processes, as well as with the understructure of the crustal mass, its previous surface form, and the attitude in which it is slowly or rapidly placed by uplift; second, the various members of a group of forms produced by a given process at any stage in its action on a given structural mass are reasonably related to one another; and, third, the groups of forms produced in successive stages of an undisturbed cycle follow in systematic order from the initial stage, when uplift begins, through many sequential stages during uplift and after it ceases, to the long-delayed ultimate stage when erosion is essentially completed.

In the first study of a sequence of type-forms produced by any one erosional process, it is helpful to assume, temporarily, that the cycle of erosion is introduced by a relatively simple upheaval of a lowland underlaid by homogeneous rocks. Complications of various kinds[1] may be examined later, especially with regard to the structure and previous form of the uplifted mass, to the rate of uplift and the nature and amount of deformation associated therewith, to various kinds of erosional processes as affected by climate and otherwise, and to the recurrence of deformation before the cycle reaches its end. An essential element in this method of physiographic study, and one that is often overlooked in geological as contrasted with

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[valleys] will be narrow and steep walled in regions of relatively rapid elevation, but broadly open in regions that have risen slowly. . . . . Rate of elevation is thus of greater importance than climatic conditions in giving the cañon form to a valley. . . . . Great cañons can occur only in young plateaus." Maturity is entered upon "as the valleys increase in number and open widely so as to consume a good share . . . . of the plateau mass. . . . . The stream courses . . . . branch and subdivide in all directions." As "the plateau passes from maturity to old age, the relief of the surface diminishes . . . . the valleys increase greatly in width, the slopes become gentler and the whole aspect of the region is simpler and tamer than before. . . . . The longest enduring outliers stand scattered about on the low plains into which the all-consuming valleys have grown. . . . . At last even these remnants are carried away, reducing the once rugged country to almost as low, flat and featureless a surface as it was at birth; but . . . . still it rises gently between the streams in faint swells which distinguish it from the more nearly perfect level of unworn surfaces. This is simple old age, a second childhood in which infantile features are imitated and thus the decrepit surface must wait . . . . until . . . . regenerated by elevation into a new cycle of life."

[1] W. M. Davis, "Complications of the Geographical Cycle," *Report, Internat. Geogr. Congr. Washington* (1904 and 1905), pp. 150–63.

physiographic treatment of earth-surface problems, is that the pre-uplift form of a crustal mass should be explicitly stated; for every crustal mass must, at the initiation of a new uplift, have a surface form, and this form must be the expression of its pre-uplift history as dependent on its internal structure, its diastrophic experience, and its external erosion. The surface form of a land mass should, indeed, be specified whenever a movement of the mass enters into a physiographic problem; for although geological discussion is concerned largely with subsurface structure which is not altered by mere uplift, physiographic description is primarily concerned with surface form; and the form that an uplifted structural mass gains by erosion consequent upon the uplift cannot be clearly understood unless the form before uplift is explicitly stated; but in the description of a land surface that has become, after and in consequence of its uplift, mature or old, the then-vanished pre-uplift form loses importance.

Many elaborations of the simple original scheme of the cycle of erosion, which applied only to humid climates, have been brought forward. My own fullest statement of them is based on a course of lectures given as visiting professor at the University of Berlin in the winter of 1908–9.[1] One of the most critical analyses of a special process is given by Johnson in his study of the cycle of marine abrasion, and in his detailed application of it to our northeastern coast.[2] A more general discussion of land sculpture is to be found in Walther Penck's *Morphological Analysis*,[3] written shortly before

[1] *Die erklärende Beschreibung der Landformen* (Leipzig, 1912; 2d ed., 1920).

[2] D. W. Johnson, *Shore Processes and Shoreline Development* (New York, 1919); *The New England-Acadian Shoreline* (New York, 1925).

[3] *Die Morphologische Analyse* (Stuttgart, 1924). This analysis is defined as a procedure by which the nature of crustal movements is to be inferred from external processes and surface forms; hence physical geology is its object and physiography is only its means to that end (p. 5). In illustration of the overformal presentation of familiar matters, a passage may be quoted from an introductory statement of "fundamental principles": "Man sieht auf der Erde nicht den durch Erosion erzeugten Formenschatz, sondern nur ein durch die Hangentwicklung allein erzeugtes Relief. . . . . Der erodierende Fluss schafft den Vertikalabstand zwischen Höhe und Talsohle, die Abtragung aber die Böschung, die körperliche Fläche, welche die Talsohle mit der Höhe wirklich verbindet. . . . . Man sieht also gar nicht die vertikalen Einschnitte, welche das fliessende Wasser erzeugt, sondern nur Hänge, die aus den einschneidenden Flüssen, *während* diese Flüsse einschneiden, in bestimmter Gestaltung emporwachsen" (p. vii). The emphasis given to this elementary truism would seem to imply that it had not

and published shortly following his lamented death, which occurred soon after he had been appointed professor of geology at the University of Leipzig. His volume contains a restatement of various established principles as well as the announcement of certain new ones, the latter being based in part on the author's observational experience in Argentina and elsewhere, and in part on his well-developed deductive faculty as well as upon his wide reading; and thus constituted the whole is profitable although sometimes difficult reading.

CLOSE ASSOCIATION OF DIVERSE EROSIONAL PROCESSES

Although cycles of erosion under diverse erosional processes may be profitably examined separately, as if they ran their course independently in different regions, it is manifestly possible that various processes may work in close association with one another in the same region. Thus when a coastal belt of whatever structure is upheaved to a great altitude, glacial erosion may act along its crest, while humid erosion acts along its seaward slope, marine erosion acts along its shore, solvent erosion in its limestone areas, and arid erosion on its nearly rainless inland slope. The Cascade Mountains of our Northwest perhaps realized this co-operative ideal during the Glacial period.

Moreover, the blending or merging, of two processes may take place, as in the transitional area between a region of abundant rainfall and a contiguous desert region. Such blending of humid into arid erosion may be found along the Pacific Coast of the Americas in middle latitudes, north and south. This clearly suggests—but does not prove—that the processes and products of arid erosion may be regarded as climatic modifications of those of humid erosion, as will be further considered below.

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been previously well understood in Germany. His critical discrimination in the use of terms is illustrated in connection with recently uplifted peneplains, which most physiographers have been content to describe as such while fully recognizing that they have suffered more or less areal degradation as well as linear dissection in consequence of their uplift. W. Penck, however, distinguishes by name between a lowlying peneplain (*Endrumpf*), still in the penultimate stage of a long-undisturbed cycle of erosion, and the slightly modified surface form (*Primärrumpf*) of the same mass as soon as it begins to suffer elevation.

ROCK FLOORS IN ARID REGIONS

Among the most peculiar and significant forms produced by arid erosion are the slanting rock floors of smaller or larger extent, which Gilbert[1] long ago described in his study of the Henry Mountains, to which McGee[2] later called attention in his explorations of the Southwest, of which Ogilvie,[3] Paige,[4] and Lawson[5] gave further account, and for which Bryan later proposed the name of "mountain pediments."[6] It is significant that all these six American observers appealed, although in somewhat different ways, only to ordinary, present-day processes of arid erosion in explanation of the rock floors that they examined.

Now that such rock floors are well known it is profitable to recall the astonishment that they earlier excited. McGee recorded that an observer "finds it difficult to trust his senses when he perceives that much of the [intermont] valley-plain area [in Arizona and Sonora] is not alluvium, but planed rock similar to or identical with that constituting the mountains. . . . . Both mountains and plain (in large part) are carved out of the same rock." The rock plain "carries but a veneer of alluvium so thin that it may be shifted by a single great storm. . . . . The vast plains [of Sonora], diversified by scattered sierras and buttes, do not represent an alluvium-buried mountain land so much as a planation level with a few monadnocks surviving." Paige also told, as if with surprise, of rock-cut piedmont surfaces in New Mexico, which ascend gently "with a profile concave upward and terminate abruptly against a mountain flank of considerable steepness"; and he noted that, when seen in distant view, these gently slanting surfaces have remarkably even profiles which truncate rock structures indifferently.

[1] G. K. Gilbert, *Geology of the Henry Mountains, Washington* (1877).

[2] W. J. McGee, "Sheetflood erosion," *Bull. Geol. Soc. Amer.*, Vol. VIII (1897), pp. 87–112.

[3] I. G. Ogilvie, "The High Altitude Conoplain . . . . . ," *Amer. Geol.*, Vol XXXVI, (1905), pp. 27–34.

[4] Sidney Paige, "Rock-cut Surfaces in the Desert Ranges," *Jour. Geol.*, Vol. XX (1912), pp. 442–50.

[5] A. C. Lawson, "Epigene Profiles of the Desert," *Univ. Calif. Pub. Geol.*, Vol. IX, (1915), pp. 23–48.

[6] Kirk Bryan, "The Papago Country, Arizona," *U.S. Geol. Surv. W. S. Paper 499* (1925).

Similar but more nearly level and much more extensive rock floors, here and there surmounted by abruptly rising residual mountains for which the name *Inselberge* is used by German geographers, occur in the drier parts of Africa, where their unexpected discovery thirty years ago almost excited incredulity. They were first described by Bornhardt, who proposed an elaborate explanation of them in terms of successive changes of level with alternations of erosion and deposition.[1] They were afterward examined in detail by Passarge,[2] who some years later followed an informal suggestion of von Richthofen's in explaining them as the product of repeatedly changing climates, the deep-weathered soils of humid epochs being removed in the following arid epochs. Hence, he concluded that *Inselberge* are *Vorzeitsformen*, the work of past conditions and not now in process of formation.[3]

Several other German observers have adopted less specialized explanations. Thus Jaeger[4] treats rock floors and their surviving island mounts as representing a far-advanced stage of erosional processes; earlier stages include the cutting of steep-walled river valleys and the retreat of the valley walls under the attack of the weather. Similarly, von Stapf[5] regards the *Inselberge* of East Africa as resulting from an extreme yet fully normal operation of destructive processes in a late stage of a cycle of erosion, and believes that as such they may be formed in any climate. These simpler views are decidedly an advance on the elaborate schemes proposed by Bornhardt and Passarge; indeed, the emphasis given by the two more recent writers just cited as to the sufficiency of normal erosional processes may perhaps represent their reaction from the inadequate views of the two earlier writers. But an explanation that applies equally to the abruptly rising *Inselberge* of desert rock floors and

[1] W. Bornhardt, *Oberflächengestaltung und Geologie Deutsch Ost-Afrikas* (Berlin, 1900).

[2] Siegfried Passarge, *Die Kalahari* (Berlin, 1904); also "Rumpfflächen und Inselberge," *Zft. deut. Geol. Gesellsch.*, Vol. LVI (1904), pp. 193–215.

[3] S. Passarge, *Beschreibende Landschaftskunde* (Hamburg, 1920), Vol. II. Also "Das Problem der Skulptur- Inselberglandschaften," *Pet. Mitt.*, Vol. LXX (1924), pp. 66–70 and 117–20.

[4] Fr. Jaeger, "Das Hochland der Riesenkrater . . . . ," *Mitt. deut. Schutzgeb., Erghft 8* (Berlin, 1913).

[5] H. von Stapf, "Beiträge zur Geomorphogenie und Tektonik Deutsch-Ostafrikas," *Arch. f. Biontologie*, Vol. III (1914), pp. 73–224.

to the residual hills of smoothly concavo-convex profiles in moist climates does not sufficiently discriminate between the unlike processes and products of humid and of arid erosion.

Obst[1] and Waibel[2] also accept normal erosion as sufficient for the production of island-mount landscapes, but again without a sufficient analysis of the problem therein involved. The last-named author states as an important generalization that degradation (*Abtragung*) on arid plains works faster than river erosion, and regards this evident relation of subaerial wasting and washing to river-cutting, a relation which manifestly characterizes the later stages of an erosion cycle, as the chief cause in the formation of arid rock floors with their surviving island-like mounts. The emphasis thus given to so simple a matter makes one wonder with what views as to the varying relations of river-erosional and general-degradational processes during the progress of a cycle of erosion this observer entered upon his African explorations!

W. Penck believed that the weakening of river erosion to still-stand is decisive for the production of *Inselberge*, but denied the occurrence of an angular change of slope at their base; and like von Stapf, he concluded that *Inselberge* are perfectly normal members in the series of degradational forms which a region assumes in consequence of a sufficiently long, undisturbed relation to baselevel, and that *Inselberglandschaften* may occur in all climates as the result of general destructional processes.[3] But his first statement overlooks the slow degradation that rivers continue to perform after they are graded while their load slowly decreases; the second contradicts the testimony of many observers; and the last two statements are questionable, unless they are taken to mean that bold residual mounts with bare rocky slopes descending abruptly to barren rock plains in arid climates are to be identified with gently sloping, soil- and plant-covered residual mounts and mounds that curve down gradually to soil- and plant-covered peneplains in humid

[1] E. Obst, "Das abflusslose Rumpfschollenland in N.-O. Deutsch-Ostafrika. Teil II: Länderkundliche Beschreibung," *Mitt. Geogr. Gesellsch.* (Hamburg, 1923), p. 35.

[2] L. Waibel, "Gebirgsbau und Oberflächengestalt der Karrasberge in Südwestafrika," *Mitt. deutsch. Schutzgeb.*, Vol. XXXIII (1925), pp. 2–38, 81–114; see especially pp. 83, 105.

[3] *Morphologische Analyse* (1924), pp. 157–61.

climates. Such forms are, truly enough, homologous, as will be more fully shown below; but they are so strikingly unlike that they ought not to be confused. It may be well believed that the two kinds of residual mounts produced in arid and in humid climates are the extreme members of a series, the intermediate members of which grade into each other in climates of intermediate quality; but it would be unfortunate not to recognize and to analyze the pronounced differences between pure-bred examples at the opposite ends of this series, even though their resemblances are also pronounced, as will be pointed out on a later page.

Accounts of various African rock floors are published by several English explorers, but with less attention to their origin than is given by the above-cited German authors. Thus Muff, in a report on Uganda in British East Africa, tells of plains of gneiss, over which bold hills and peaks rise in residual forms.[1] Falconer describes an interior area of Nigeria, known as Hausaland, north of the equatorial rain-belt in West Africa, as an open plain reaching to the horizon, partly covered with sands, partly exposing bare rock, with gentle undulations following one another in endless succession. Geological processes there seem to have come to a standstill. The rivers follow poorly defined, shallow, soil-covered depressions in the plain. Here and there a group of boulders, a low "turtleback," or a knob of granite rises. In another part of Nigeria, exfoliating domes of bare granite (Fig. 1), with a basal talus of rock slabs, surmount an extensive rock plain.[2] Similarly, Holmes and Wray state that inland from a low coastal belt in Mozambique, south of the equatorial rain-belt in East Africa, a vast plateau of gneiss and granite rises gradually but steadily westward from the low coastal border with remarkable regularity to an altitude of 3,000 feet in 250 miles; its even surface is diversified by single or grouped hills—naked domes, knobs, or pinnacles—the barren flanks of which rise abruptly over a litter of flaked-off débris at the base. The rivers flow in broad, shallow, gravelly channels, not incised below the plain.[3]

[1] H. B. Muff, "Geology of the East-Africa Protectorate," *Colon. Reports*, No. 45 (1908).

[2] J. D. Falconer, *Geology and Geography of Northern Nigeria* (London, 1911).

[3] A. Holmes and D. A. Wray, "Mozambique, a Geographical Study," *Geogr. Jour.*, Vol. XLII (1913), pp. 143–52; also *Geol. Mag.*, Vol. IX (1912), pp. 412–17.

Collie is, as far as I have read, the only American geologist who has written on African rock floors. The area that he examined is the semiarid gneiss province of middle East Africa. Its deformed structure suggests a former mountainous topography, but it is now largely reduced to a peneplain which, while still bearing many residual mounts, slopes gradually eastward from a loftier and rainier plateau country farther inland to a lower and rainier belt along the coast. The intermittent streams which cross it accomplish little corrasion; they are chiefly concerned with transportation of detritus, derived from the rainier western plateau and in part spread out on

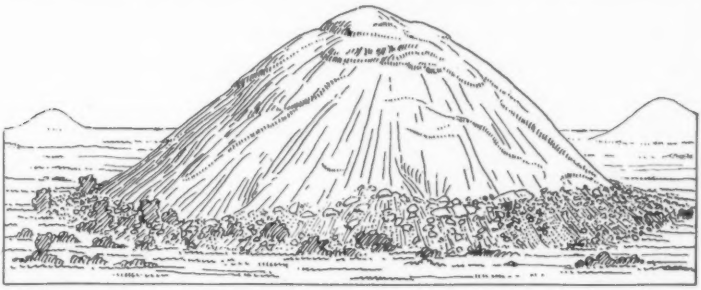


FIG. 1.—An island mount, showing exfoliation of granite, in the Kilba Hills near the east boundary of Nigeria, 70 miles north of Benue River. (Outlined from Falconer Plate VIII.)

the peneplain in sheet-flood fashion. Hence the "wet belt of the high plateau can not be degraded any faster than the semi-arid belt permits."[1]

Widespread rock floors have lately been described by Berkey and Morris in Mongolia. These observers report that, in one instance, an extensive piedmont rock slope is carved "by an infinite network of shallow rill courses, and is thinly and unevenly strewn with small chips of native rock"; the chief rôle in eroding the slope is "ascribed to the myriad short-lived streamlets acting on the weathered rock of the piedmont"; they "may run together in little drainage systems" or "may die out leaving a thin flat cover of angular fragments over the slope. . . . . Here and there, masses

[1] G. L. Collie, "Plateau of British East Africa," *Bull. Geol. Soc. Amer.*, Vol. XXIII (1912), pp. 297–316.

of upstanding rock are left towering above the nearly smooth surface. Just why they should be spared in the general planation it is often difficult to see. . . . . The whole piedmont slope becomes lowered very gently as the graded streams cut downward, and becomes lengthened very slowly as the mountain front is cut away."[1] These bare rock floors in Mongolia, and still more the basins excavated beneath them, appear to testify to the effective exportation of dust from vast interior drainage basins by the prevailing westerly winds; nowhere else has this theoretical expectation received so vivid a verification.

A west Australian arid region has been described by Jutson[2] as having in part a gently undulating surface, but as being remarkably level over large areas and apparently rock-floored.

MOUNTAIN PEDIMENTS IN ARIZONA

The best account of mountain pediments (rock floors) in Arizona is that above cited by Bryan, who explains them by a long continuance of the arid processes of erosion now acting there in the destruction of the desert mountains, as will be more fully set forth below. This simple explanation has lately been cordially adopted by Waibel, whose field studies in Arizona and Sonora carried him, with Bryan's aid, to a much fuller understanding of arid erosion than he had earlier reached in his exploration of Africa, and whose conclusions therefore merit our careful attention.[3] He contributes the further idea that the great development of nearly level rock floors in arid Africa where the *Inselberge* are of relatively small extent, in contrast with the smaller development of gently slanting pediments in Arizona where the mountains are of larger extent, is a consequence of long-enduring quiescence after more ancient deformation in the

[1] C. P. Berkey and F. J. Morris, *Geology of Mongolia* (New York, 1927).

[2] J. T. Jutson, "Land Forms in Subarid Western Australia," *Geogr. Jour.*, Vol. XL (1917), pp. 418–34; also "Physiographical Geology of Western Australia," *Geol. Surv. W. Aust. Bull. 61* (1924).

[3] Leo Waibel, "Die Inselberglandschaft von Arizona und Sonora," *Jub. Sonderb. Gesellsch. Erdk.* (Berlin, 1928), pp. 68–91. He writes: "Zu meiner Freude konnte ich feststellen, dass die Bryanschen Resultate in allen wesentlichen Punkten mit meiner in Sonora gewonnenen Auffassung übereinstimmen. Was aber bei mir infolge der flüchtigen Bereisung mehr Vermutung und Hypothesen war, das fand ich bei Bryan durch eine grosse Menge von exakten Daten belegt und zur Gewissheit erhoben" (p. 72).

first region in contrast to a relatively short period of quiescence after more modern block-faulting in the second region; in other words, that the broad rock floors of Africa represent an advanced stage of a long-undisturbed cycle of arid erosion operating on a former highland now almost consumed, while the narrower American pediments represent an earlier stage in an arid cycle operating on various fault-block mountain masses which still survive in greater or less volume.

During three successive spring terms, 1927–29, at the University of Arizona in Tucson, I have had opportunity of examining several mountain pediments, as follows: One of moderate area, worn down on deformed Cretaceous strata along the western base of the Tucson range, has been shown to me by Professor W. H. Brown, of the State University; Mr. Carl Lausen, of the United Verde Copper Company, has guided me to a larger pediment developed around the Sierrita Mountains, some 20 miles farther south; the well-developed pediment of the Sacaton Mountains, some 70 miles northwest of Tucson, taken as a typical example by Bryan, has been visited in company of Professor J. W. Hoover, of the State Teachers College at Tempe, near Phoenix; and several incipient pediments, forming recesses of limited dimensions along the northwest base of the Santa Catalina Mountains, 20 miles north of Tucson, have lately been studied with one of my students. When the well-developed Sierrita pediment is seen from a distance, its profile slants outward from the surviving mountain core with astonishing smoothness at an angle of 4° or 3°; indeed, it seems truly rectilinear as it passes from degraded rock to aggraded alluvium until, several miles forward, the declivity gradually decreases to the nearly level floor of an intermont trough. The delicate precision of the distant profile gives it a beauty that one would hardly expect in a line of such simplicity; yet when closely inspected on the ground, this pediment is found to be openly trenched along most of its stream lines to a depth of 10 or 15 feet, as if in process of redegradation to a slightly lower level, perhaps in consequence of a faint change of climate.

A vastly greater rock floor of penultimate degradation is believed to have been developed over a large part of Arizona, and probably in adjacent states as well, during late Tertiary time, before the fraction of it which is now included in northeastern Arizona was

given its present plateau altitude, stripped of its weaker covering strata, and trenched by the Colorado canyon, and before its western part was broken into the fault blocks of the Basin ranges. This uplifted and dislocated rock floor is of historic interest in its northeastern or plateau area because of having been recognized as a surface of extensive degradation by Newberry, who as long ago as 1857 saw that it represented "a much grander monument of the power of aqueous erosion than even the stupendous cañon of the Colorado."[1] A general account of part of the same rock floor was given by Dutton;[2] and a more detailed description of it, especially of those parts which have been protected by lava covers from revived erosion in consequence of later uplift, has been prepared by Robinson.[3]

Besides these Arizona examples of rock floors I have had opportunity of inspecting in a general way a number of others in southeastern California, chiefly in company with Dr. L. F. Noble, of the United States Geological Survey; brief references to them have been made in a special paper[4] in which, however, while the rock floors were set forth systematically in order of areal development, they were described chiefly in view of their association with fans of outwashed detritus.

HUMID HOMOLOGUES OF ARID ROCK FLOORS

Although the gradual climatic transition that is often found from a region of humid erosion to one of arid erosion strongly suggests that, as noted above, the processes and forms of such regions merge into one another, and that the cycle of arid erosion may therefore be treated as a climatic modification of the cycle of humid

[1] T. S. Newberry, in Ives' "Report on the Colorado River of the West" (Washington, 1861) *Geology*, Part III, p. 86.

[2] C. E. Dutton, "Tertiary History of the Grand Canyon District," *U.S. Geol. Surv. Monogr. II.*

[3] H. H. Robinson, "The Tertiary Peneplain in Arizona and New Mexico," *Amer. Jour. Sci.*, Vol. XXIV (1907), pp. 109–29. "The surface of the entire southern plateau country in northeastern Arizona south of the Colorado canyon . . . . had been reduced to a peneplain" (p. 111); in the Little Colorado valley "the surface of the peneplain was one of practically no relief" (p. 114); "the peneplain may be traced over very considerable areas by means of the basalt which caps its surface" (p. 115).

[4] W. M. Davis, "The Basin Range Problem," *Proc. Nat. Acad. Sci.*, Vol. XI (1925), pp. 387–92.

erosion, this view has been questioned by an experienced German writer.[1] It would consequently seem that, in spite of the nearly fifty years of age now reached by the simplest scheme of the cycle of erosion, and of the nearly twenty-five years of age reached by the application of the scheme to arid conditions,[2] this application needs fuller explanation.[3] The object of the present essay is therefore twofold. First, to set forth in some detail the facts and arguments which have, during my recent residence in the Southwest and in spite of the adverse opinion just cited, confirmed an earlier

[1] His conclusion is, in effect, that the attempt to explain arid erosion of rock floors as a climatically controlled modification of the cycle of humid erosion must be regarded as a failure. This conclusion is perhaps based on his misunderstanding of the meaning given by American geologists to the term "erosion." We take it to include subaerial degradation in general as well as river corrasion, while German writers ordinarily use separate terms, *Erosion* and *Abtragung*, for these closely associated destructive processes; yet even German writers tell of *Erosionsgebirge*, in the production of which *Abtragung* has done enormously more work than *Erosion*. The German usage of the two words is illustrated in a passage quoted from W. Penck's *Morphologische Analyse* in footnote 3, p. 3.

[2] W. M. Davis, "The Geographical Cycle in an Arid Climate," *Jour. Geol.*, Vol. XIII (1905), pp. 381–451. This essay treats chiefly the gradual integration of initially independent interior drainage areas and their reduction to extensive rock plains as dust is exported from the lowest central basin floor. The form of the surrounding mountains is not particularly considered.

[3] A number of European geographers have failed in various respects to understand the spirit of the cycle scheme. They have criticized it as too largely deductive, without seeing either that its basis is essentially inductive or that the deductive form often given to it is merely a matter of presentation. They have misconceived it as rigid, thus failing to recognize its elastic applicability to all sorts of natural conditions. One of them has objected that it could not hold good for the Alps because of the several movements that those mountains have suffered, thus implying that the scheme always demands a complete cycle and overlooking the plain possibility that interruptions by movements at any stage of its progress are among the most manifest of its many complications. Another refuses to call the valley of a single river mature where it is openly excavated in weak rocks and young where it is narrowly incised in resistant rocks, and protests that a single valley must be of the same age all along its length; thus failing to recognize that young and mature as here used refer to stages of development and not to age measured in years. A third insists that the scheme takes no account of erosion during the uplift of a land mass, although explicit account of such erosion has repeatedly been given. A fourth condemns the explanation of adjusted drainage, inherent in the scheme, because it fails to apply in a case where it really has no application. Finally, the scheme of the cycle has been pronounced dangerous, because it may be misused by students who are not fully trained in its proper use. All these objections seem to me to arise from a too literal following of various brief expositions of the scheme, without grasping the spirit that is behind them, and that has been clearly indicated in fuller expositions.

belief that the cycle of arid erosion may be, with all its peculiar consequences, reasonably treated as a variant of the cycle of humid erosion, even to the point of relating the typical boulder-clad mountain slopes and their débris-strewn piedmont pediments or rock floors in arid regions to the corresponding and truly homologous features in humid regions; and, second, to make clear, by following the teachings of Lawson and Bryan, that although arid erosion resembles humid erosion in many respects, the two kinds of erosion nevertheless differ so much in process and in product that they cannot be clearly understood if they are briefly brought together as examples of normal erosion, as has been done by several of the German writers above cited. The unlikenesses of the two erosions deserve explicit treatment. In order to justify these statements, the processes of arid erosion and the forms that they produce will first be reviewed; the processes of humid erosion and the resulting forms will next be reviewed; and a comparison will then be instituted between the two classes of processes and of forms in order to make clear the striking homologies that exist between them. These reviews and the comparison to which they lead will involve much familiar matter, which it seems advisable to set forth in some detail in order to gain a clear entrance into the problem under consideration.

ORIGIN OF PEDIMENTS

It seems that Gilbert was one of the first observers to recognize, to describe, and to explain the slanting rock floors of arid regions, now called "pediments"; for he discovered them, overstrewn with flood-plain detritus to be sure, around the arid Henry Mountains of southern Utah in 1875, but he did not give them any special name. His explanation of the examples that he saw was that they result from the planation of inclined strata by streams which radiate from the laccolithic mountains that he was then studying; for the streams having removed a great volume of overlying rock and being now chiefly occupied with the transportation of an abundant load, erode laterally until their slanting plains, almost unaffected by differences of rock resistance, coalesce. "Where the load reduces the downward corrasion to little or nothing, lateral corrasion becomes relatively and actually of importance. . . . . The process of carv-

ing the rock so as to produce an even surface and at the same time covering it with an alluvial deposit, is the process of planation."[1] As these rock-floors are rather heavily gravel-covered, they received little attention, and it was not until McGee, twenty years later, described the much larger bare-rock plains of Arizona, as noted above, that the importance of such surfaces was recognized. He ascribed them chiefly to sheet-flood erosion, which is undoubtedly an important process in their advanced development.

Thirty years after Gilbert, another approach to the explanation of pediments by present-day processes, much in the way that was later more fully set forth by Paige, Lawson, and Bryan, was made in the paper by Ogilvie above cited; it gives an account of the Ortiz Mountains in New Mexico, where an arid, out-sloping plain surrounding the dissected mountains and called a "conoplain" is described as partly cut back across the deformed rocks of the mountain mass and as partly built forward by deposition of mountain waste. The conoplain is held to be peculiar in not being related to normal baselevel, by reason of the dwindling-away of the mountain-fed streams on the dry peripheral slopes. The more advanced stages of such a plain, in which it will be dissected and worn down in relation to normal baselevel, if it does not stand in an interior basin, by the headward gnawing of neighboring river systems, and in which the central mountains will be consumed, are not discussed.

The explanatory scheme for the production of pediments adopted by Paige, Lawson, and Bryan is, in its briefest form, as follows: A steep-sloping mountain front is worn back at a constant declivity by the ordinary subaerial processes of mountain recession as controlled by arid weathering and washing. Below the mountain front the worn-down surface of the rock floor—the pediment—is at first narrow, rather steep, and covered with a graded embankment of alluvium. But the embankment gradually rises, parallel to itself, because its lower end reaches the rising detrital floor of an infilling intermont basin; and as it rises it overlaps farther and farther on the growing pediment which, as it broadens, becomes less steep and almost bare. In other words, as the mountain front recedes the pediment and the embankment are extended in pursuit of it. Paige

[1] *Geology of the Henry Mountains* (1877), pp. 120–23.

and Bryan give attention chiefly to the pediment at a medial stage of its development; Lawson, who calls the pediment a suballuvial bench, gives a keen and penetrating deductive discussion of its development through all the stages of a complete cycle of arid erosion, and adduces a number of actual examples in support of his deductions. His analysis of the pediment or rock-floor problem is much fuller than that given by any other observer, American or German. He emphasizes a point that Paige had previously noted, namely, that the suballuvial bench, having a convex profile, Figure 2, will be normally overlapped by the aggrading detrital embankment of

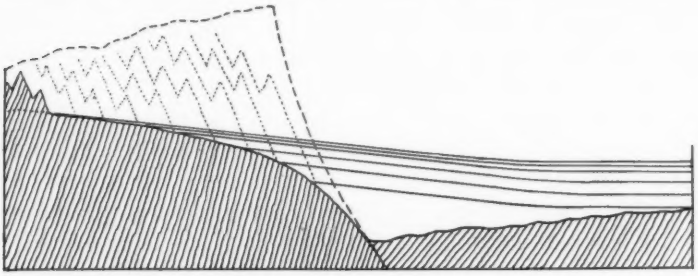


FIG. 2.—Profiles, based on Lawson's figure, to illustrate the retreating face of a fault-block mountain, and the associated development of its suballuvial rock bench or piedmont pediment with its aggrading and overlapping alluvial embankment. Slopes are exaggerated.

very perceptible and essentially constant declivity,[1] which as it rises becomes the asymptote of the growing bench-hyperbola. Eventually the rock crest of the mountain mass will be completely consumed, and the embankment will then thinly and discontinuously overlap the rock bench all the way to the truncated summit.

A revelation of the suballuvial bench may, however, occur before so extensive a retreat of the mountain front takes place, yet at so late a stage of the systematic sequence of changes that the decreasing declivity of the bench comes almost to coincide with the essentially constant declivity of the detrital embankment; whereupon "the suballuvial bench becomes a subaerial bench, across which the detritus from the vanishing mountain front is swept in times of

[1] Lawson, *op. cit.*, pp. 31, 35.

cloud-burst, to be spread over the surface of the embankment below. This emergence of the bench and its persistence as a subaerial feature appears to be most characteristic of granite ranges which disintegrate into fragments composed chiefly of the individual mineral constituents, and therefore very uniform in size."[1] It is particularly the bench thus, according to Lawson, revealed, that Bryan has described under the name of "mountain pediment." Let it be noted, however, that the revelation of a suballuvial bench will be favored not only if the above-specified conditions arise but also if the arid basin into which the alluvial embankment slants down has, not a rising surface due to aggradation by inwashed detritus, but a lowering surface due to exportation of dust by wind in excess of the detritus inwashed by water. Wind action is, however, little considered in Lawson's discussion.

An even more effective cause for the stripping of detritus from a growing pediment is found in the capture, by a lower basin, of the centrifugal drainage that leads into a higher basin; for such captures must sometimes take place during the slow progress of drainage integration by which the cycle of arid erosion is characterized, as will be further told below. The revival of erosion in all parts of a higher basin in consequence of such a capture will cause not only the stripping of alluvium from the peripheral pediments but also their dissection and degradation to a lower level than before. Various empirical accounts of the highlands of Tibet suggest that this process is at work there, in a few instances at least; but in the lack of understanding of the process by most explorers their records leave the matter in doubt. Into this aspect of the problem it is not necessary to enter here.

Lawson goes on to show that bare-rock slopes may be developed in still another manner. A diastrophic movement or a climatic change may "promote the destruction of the alluvial embankment," and "then we may by resurrection have the suballuvial bench revealed as an element in the visible profile."[2] In this connection

[1] *Ibid.*, p. 37. It will be further explained below that the probable cause for the eventual emergence of the rock bench chiefly in granitic ranges is that granitic rocks alone occur in large-enough masses of uniform resistance to permit the advanced development of the bench the emergence of which takes place.

[2] *Ibid.*, p. 34.

approving reference is made to Paige, who is said to have been the first observer who correctly interpreted bare-rock slopes "as resurrected surfaces due to the stripping of the alluvium which once rested upon them," instead of accounting for them directly, as McGee did, by sheet-flood erosion.[1] Here again, if the waste basin to which the alluvial slope drains is in process of being lowered by wind exportation of dust, it would seem that a slow removal of the alluvial embankment and revelation of the underlying rock floor may take place without diastrophic movement or climatic change.

DIVERSE DEVELOPMENT OF MOUNTAIN PEDIMENTS

The pediments of different mountain masses may manifestly be in different stages of development, as dependent either upon the nature of their rocks; or upon the time since the mountain mass, on assuming its present attitude, entered upon the cycle of arid erosion now current. For example, of the several ranges which partly inclose the broad, aggraded basin of Tucson, in southeastern Arizona, the lofty Santa Catalina Mountains on the north are but moderately worn back in incipient pediments of small width along part of the northwest fault-margin, while along the rest of that margin, as well as along their southern border, they are cut down only in narrow-mouthed canyons along moderately sinuous base lines which very clearly transect their deformed structures; and around a good part of these two margins the gravel outwash slope or *bajada* (*bahada*) is now curiously disordered and dissected, but that is another story.

On the other hand, the well-dissected and much-reduced Sierrita Mountains on the southwest are only comparatively small residuals of modest altitude and subdued form, which with a number of larger or smaller outliers rise from the beautifully developed rock floor and detrital slope above described; and to the south of the Tucson basin-plain the Santa Rita Mountains, of intermediate height with elaborately dissected slopes and an irregular margin, are flanked on the north at least by an extensive *bahada*, the fan-heads of which, entering every valley mouth with a slant of 5° or 4°, gradually flatten as they slant forward several miles to the Tucson plain; and although

[1] *Ibid.*

the fans are dissected in their upper parts, perhaps by reason of a slight climatic change,[1] to depths of from 20 to 40 feet, not a sign of a rock pediment is revealed. The very unequal measures of dissection in the *bahadas* of these neighboring mountains suggest that some other factor, or factors, besides changes of climate have been involved in the reversal of their aggradation into degradation.

MOUNTAIN FACES BACK OF PEDIMENTS

A peculiar feature of the mountains, large or small, which rise from many of the well-defined pediments in Arizona, as well as of the small-mass mounts or *Inselberge* which rise from the vast African rock floors, is the comparatively abrupt transition from one form to the other. An almost angular change may be made from a bold and rock-faced mountain front, with a slope of 30° or 35°, to a pediment with a slope of only 5°, 4°, or less, or to the African rock plains of still more nearly level surface. This has been noted by many observers but satisfactorily explained by few. Lawson and Bryan account for it simply enough as the necessary result of a relatively sudden change from coarse débris on the mountains to finer débris on the rock floors. Bryan writes: "Transportation of relatively fine débris by water is the essential factor in the formation of the pediment," while "the erosion of mountain slopes . . . . is largely controlled by the movement of large boulders."[2] The most abrupt change of slope occurs in the case of mountains composed of massive rocks, such as granite or monzonite, which weather into large blocks between which much bare rock is exposed. If the mountain rock weathers to finer débris, the slopes are gentler, they are better concealed with the products of weathering, and they grade into the pediment by a well-developed curve.

We may now turn from this brief statement of the leading processes and forms of arid erosion and summarize the apparently differ-

[1] E. Huntington, in his study of the Tucson region, makes no mention of the pediments although he recognizes the steep and rocky mountain slopes over the gentler *bahada* slopes of gravel, sand, and silt. He notes, however, that the *bahadas* "are constantly interrupted by small valleys or gullies of recent origin," which he ascribes to climatic fluctuations. See his volume on "The Climatic Factor," *Carnegie Inst. Pub. 192* (1914), pp. 19, 31.

[2] *Op. cit.*, p. 57.

ent but really homologous features of humid regions as they are successively developed in the ordinary progress of a cycle of normal or humid erosion.

INTRODUCTION OF A CYCLE OF HUMID EROSION

In order that the forms produced in a cycle of humid erosion may be fairly compared with those produced in a cycle of arid erosion, it is desirable that all factors but climate should be alike. The mountains of our arid Southwest, described by Bryan as well as by Waibel, are believed by them and by others also to have been developed on a series of fault-blocks of disorderly displacement but of unspecified pre-faulting form; and the most striking examples of arid mountains, the steep boulder-clad fronts of which change abruptly into gently slanting pediments, consist of great masses of granite. Therefore, a series of granitic fault-block mountains will be imagined on which humid erosion may act; this assumption being reasonably made not only because granite weathers into large boulders, but also because it occurs in larger and more homogeneous masses than most other rocks. Let it also be assumed for the sake of simplicity that, before block-faulting occurred, the granitic region had been reduced to a surface of low relief, rocky and barren in the arid climate, but with a deep-weathered and damp soil bearing abundant vegetation in the humid climate; also that the potential form due to faulting—that is, the form which would be produced if no erosion took place during the progress of the faulting—was in both regions such as is indicated in Figure 3. But let the momentary assumption of no erosion while faulting is in progress be at once corrected by recognizing that, as soon as faulting is initiated, a new cycle of erosion is thereby introduced, and that erosional processes, arid in one case, humid in the other, at once set to work to destroy the uplifted surface to the best of their ability, gaining force as altitudes and slopes are increased.

The primary difference between such a series of granitic fault blocks in a humid and in an arid climate at the time of most active faulting will be only climatic; secondary differences will be immediate consequences of the unlike climates, as seen in drainage, weathering, soil, and vegetation; and tertiary differences will be apparent

as fast as topographic forms appropriate to each climate are developed. What we wish to learn is whether those forms are altogether dissimilar in the two cases, or whether they are, in spite of any unlikenesses that they may show, essentially homologous; in other words, whether the forms produced by arid erosion may or may not be reasonably explained as climatic variants on those produced by humid erosion. The discussion involves many more or less familiar matters, among which those concerned with the development of valley floors and their rock basements are the most significant in the present connection.

EARLY CONTRASTS AND RESEMBLANCES OF HUMID AND ARID DRAINAGE

In the humid region a completely integrated drainage system will be promptly developed, chiefly composed of short streams consequent upon the back slopes and of still shorter streams on the fault faces of the blocks as they are uptilted, and of lakes consequent upon the interblock basins as they are depressed; but besides there will be longitudinal consequent rivers flowing along interblock angles above lake level, and shorter consequent rivers flowing across the sags in the block crests and connecting the consequent lakes. An antecedent river may also be present, persisting in the course that it had on the pre-faulting lowland, and now flowing obliquely across the blocks without regard to their heights or slopes. All the larger rivers will rapidly cut down the lake outlets to grade and thus, if the ocean is not too distant, even the farthest-inland lakes will soon be lowered almost to baselevel; at the same time, various affluents of the lakes will cut canyons, ravines, and gulches of divers sizes and will deposit their detritus in lake-shore deltas.

In an arid region of similar initial form, the drainage will be little integrated. Most of the interblock basins will receive only short consequent streams, which will cut canyons, ravines, and gulches in the block slopes; and the resulting detritus will be deposited in the basins, thus developing what may be called "lakes of waste." The contrasts between these arid lakes of waste and the humid lakes of water is not so great as might be at first supposed; for even water lakes contain some waste, and all waste lakes contain much water;

and the apparently level surface of the water lakes really slopes in imperceptible water fans away from every inflowing stream, just as the easily seen fans of the waste lakes do. If the waste fans are much steeper than the nearly level water fans, that is merely one of the many cases of a difference of degree rather than a difference of kind between the two regions, and it is wholly of climatic origin.

Here also an occasional antecedent river may survive: witness the course of Sevier River directly through, instead of around, the

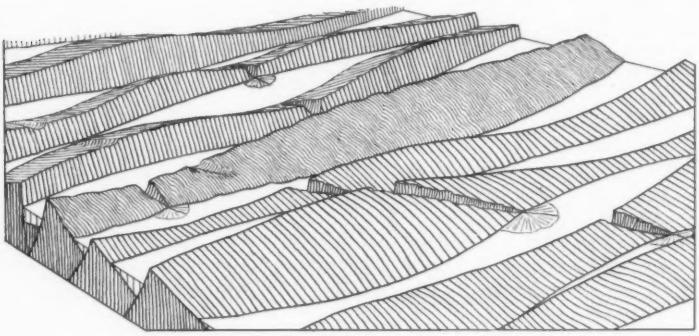


FIG. 3.—Little modified, potential surfaces of diversely tilted and warped blocks produced by the faulting of a granite lowland in a humid region. The slope of the middle block is drawn to show its pre-faulting surface of low relief. The other block slopes are drawn as if the pre-faulting surface had been a plain. Consequent transverse gorges have been cut across sags in the crests of three background blocks by the outlets of consequent lakes. Oblique gorges have been cut in line through three foreground blocks, irrespective of their height and slant, by segments of a persistent, antecedent river, the defeated work of which in three other blocks is indicated.

northern part of the Canyon range in southwestern Utah;[1] witness also some remarkable instances of antecedent drainage in the tilted lava blocks of arid northeastern California as recently described by R. J. Russell.[2]

In contrast to the prompt establishment of overflowing, lake-filled basins and of integrated drainage in the humid region, is the

[1] W. M. Davis, "The Mountain Ranges of the Great Basin," *Bull. Mus. Comp. Zoöl.*, Vol. XLII (1903), pp. 129–77.

[2] R. J. Russell, "Landslide Lakes of the Northwestern Great Basin," *Univ. Calif. Pub. Geogr.*, Vol. II (1927), pp. 231–54.

delayed filling of waste basins and the long-postponed integration of drainage systems in the arid region. But such filling and overflow will take place when higher basins are so well aggraded that their intermittent streams spill over the lowest sag in their rim and thus become tributary to a neighboring lower basin; or when headward erosion by a lower-basin stream captures a near-by higher basin before it spills over. Thereupon the detritus in the higher basin will soon be more or less completely eroded and removed, and the lowering basin floor will be worn down to grade with the filling floor of the lower basin. An incipient case of this kind may be seen in a small, high-level basin at the western base of the Argus Range in southeastern California, from which a recently developed northward discharge is now cutting a narrow and steep-walled gorge around the northern end of the range into the much lower and larger basin that lies next to the east between the Argus and the Panamint ranges. Here the overflow is so lately established that the floor of the higher basin is as yet little dissected. On the other hand, farther northeastward but still in California, a former high-level intermont basin of moderate size has become tributary to a large intermont trough known as Fish Lake "valley" near by on the west, of which the great Inyo-White Mountain Range forms the farther or western wall. Here the high-level basin is now well dissected, its new floor is graded with respect to the large trough-floor on the west, remnants of the former floor are seen in terraces, and the connecting valley is broadly open. This example of integration is evidently of earlier beginning and of greater accomplishment than the one adjoining the Argus Range.

But it is not only in arid regions that a basin of deformation may not be immediately filled to overflowing; even in a humid region a basin of small drainage area and of rapid deformation—as rapid as the uplifts near Wellington, New Zealand, in the middle, and near Yakutat bay, Alaska, at the end of the last century—would have a delayed overflow; and although the delay of filling and overflow in such a case would be short compared to the delay in arid basins, both delays are of the same kind and differ only in degree. Moreover, in nearly all humid basins, it is only the water that overflows promptly; the overflow of waste does not take place until the water

lake is waste-filled; and then the surface of the waste-filling has essentially the same kind of shape as the surface of an arid and overflowing waste-filled basin, even though the slopes are of different declivities; and this difference of declivity is manifestly due wholly to the difference of climate in the two regions. On the other hand, a contrast may be noted between the slowly aggraded surface of waste in an arid basin, which thus serves as a rising baselevel for the inflowing streams, and the slowly lowered surface of water in a humid basin which therefore serves as a sinking baselevel for the inflowing streams while the valley of the outflowing stream is deepening; but this contrast does not always obtain, for it appears from studies by Blackwelder in our Basin Range region,[1] and still more from the explorations of Berkey and Morris in Mongolia,[2] that the waste in an arid basin may be removed and its surface lowered, apparently by wind action, so that waste lakes as well as water lakes may serve as sinking baselevels.

VALLEYS DEVELOPED BY HUMID EROSION

Let attention now be directed to the forms developed on a single upheaved fault-block by stream erosion in a humid climate, not that this problem is novel, but that it must be explicitly explained in order to understand its bearings on the question before us. For convenience of illustration let the block be broadly uparched, as near the foreground of Figure 3; part of the block being shown on a larger scale in Figure 4. While elevation is still in progress, each consequent stream excavates a valley draining into a lake or trough; and each valley-cutting, consequent stream may, at an early stage of its work, be considered in three parts or courses, which blend into each other. First a headwater course where, in spite of the considerable altitude to which the stream has there been elevated, its small size prevents it from rapidly eroding a deep valley; hence it will for a time cut only a shallow valley, the sides of which will be weathered well open during the slow deepening. Second, a lower course where, in spite of the good size of the stream, it stands so little above local

[1] Eliot Blackwelder, "Origin of the Desert Basins of the Southwestern United States (Abstract)," *Bull. Geol. Soc. Amer.*, Vol. XXXIX (1928), pp. 262–63.

[2] C. P. Berkey and F. J. Morris, *Geology of Mongolia* (New York, 1927), pp. 146, 268, 329.

baselevel that it cannot cut a deep valley even after elevation is completed. Third, an intermediate course where, the stream having fair volume and the land surface gaining fair altitude, a relatively deep and steep-sided valley will be quickly eroded while elevation is in progress, at the bottom of which the stream will flow for a time as an ungraded torrent. However, short streams on the side slopes of uptilted fault blocks, such as here considered, will seldom be large and active enough, even along the intermediate course, to cut a valley with canyon walls so steep that no waste lodges upon them; the valley sides will be more or less graded and waste-covered as the fault-blocks are uptilted and the valleys are deepened. Deep,

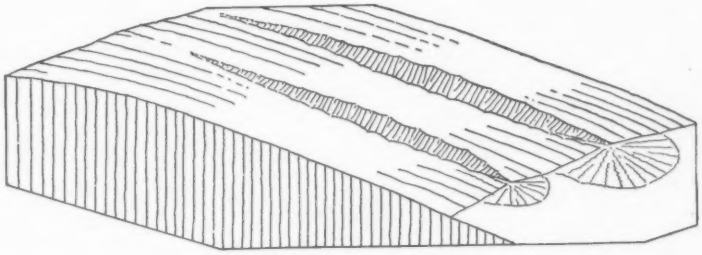


FIG. 4.—Young consequent valleys in the back slope of an upwarped fault block, on a larger scale than that of Fig. 3.

bare-walled, canyon-like valleys are expectable only along the intermediate course of large rivers.

After block-raising and valley-deepening cease, the side walls along the early graded, lower course of a stream will soon be weathered back to moderate declivity, if they are not so weathered while block-raising is in progress. In the intermediate course, where the valley will be deeper and steeper-sided when elevation ceases and the stream reaches grade, the valley may be somewhat canyon-like, as caricatured on a much-enlarged scale in the back block of Figure 5. At this stage the irregular disposition of rock joints will cause the production of many precipitous and bare rock faces, separated by less precipitous ledges on which, as coarse detritus accumulates, root-hold will be afforded for such plants as can grow in coarse, shallow, and dry soil. Wherever bare walls are thus developed in

massive rocks, fragments may break off and roll down from the rock faces in sufficient quantity to accumulate for a time as a veneer or talus at the base of the retreating slope, as shown in the second block of Figure 5. In valleys that are eroded through plateaus of horizontal, cliff-making strata, the retreat of a capping cliff will be long accompanied by a retreating, subcliff talus; but in massive rocks such as are here postulated, the talus marks only a transitory phase of valley-widening. It vanishes with the extinction of outcropping ledges on the valley-side slopes, as shown in the third block of Figure 5.

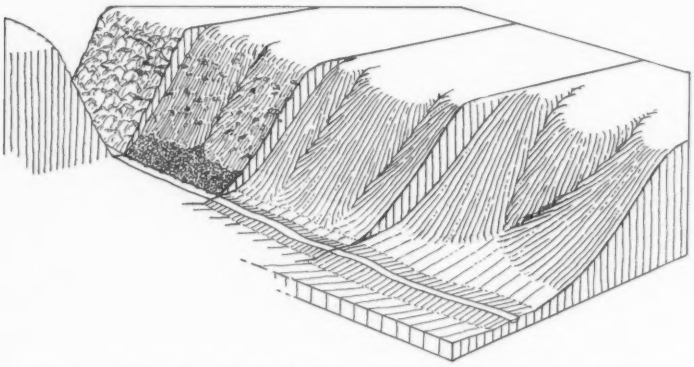


FIG. 5.—Four early stages of valley-widening, on a much larger scale than that of Fig. 4.

During the delay in the recession of the basal slope by reason of its being talus-covered, the more active recession of the bare-rock surfaces in the higher slope will decrease the average declivity of the valley sides; and then, with increasing development of a soil-cover and with the better establishment of plant growth upon it, the declivity of the valley side will be progressively lessened until all the slope above the retreating talus comes to be cloaked with finer and finer detritus and covered with an increasingly dense plant growth, as in the third and fourth blocks of Figure 5. Thereafter, the removal of the soil cover will be more and more leisurely, and the soil will therefore become much refined in texture at the surface and at the same time increased in depth.

As rill-wash and soil-creep slowly carry the finer surface soil down to the stream, in spite of the protection given to it by plant growth, underground weathering will penetrate deeper and deeper along joints and into joint-split blocks, thus dividing the subsoil granitic mass into irregular, boulder-like masses and developing coarse-textured soil in the spaces between them. The boulder-like masses will be increasingly subdivided, rounded, and disintegrated by continued weathering until, as their soil cover is slowly removed, they are themselves converted into soil and new subsoil blocks are weathered out. The subsoil blocks and the coarse interstitial débris stand still, while the overlying finer soil slowly washes and creeps downslope past them; and by the time the removal of the outer soil to the valley bottom has been accomplished, the sluggish underblocks are themselves disintegrated and their débris is in its turn slowly removed, while new and deeper-lying subsoil blocks are weathered out.

During these early stages of valley growth the cross-profile of an intervalley ridge will still be nearly flat-topped, if the uplifted block be part of a former peneplain as is here assumed to be the case; but as the valleys widen, the cross-profile will become broadly convex, yet retaining for a time a somewhat "square-shouldered" form on either side, where the more pronounced descent into the valley begins. This is all familiar enough, and it is restated here simply in order to secure a clear entrance into what follows.

[*To be concluded*]

WEATHERED ZONES OF THE DRIFT-SHEETS OF ILLINOIS[1]

MORRIS M. LEIGHTON AND PAUL MacCLINTOCK

ABSTRACT

A study of the weathered zones of the various drift-sheets of Illinois reveals that they consistently comprise four subdivisions, regardless of topographic or vegetative environment, but that the zones nevertheless show characteristic responses to topographic position and to drainage conditions. In well-drained areas the *silttil profile* has developed, in poorly drained areas the *gumbotil profile* has developed, and in partially drained areas the *mesotil profile* has developed.

The Wisconsin and Iowan drift-sheets show immature profiles but the Illinoian and older drift-sheets show, respectively, early-mature to mature profiles. It seems probable that silttil profiles of one area may be correlated with gumbotil profiles of another area.

In the older drift-sheets where erosion has worked headward into a broad flat area, the gumbotil profile of weathering may show in its upper portion the beginning of a second profile due to the newer and better drainage conditions. "Fossil" weathering profiles buried beneath later deposits reveal the conditions that prevailed during the interglacial stages in which they were developed.

INTRODUCTION

When a geologist observes weathered glacial drift under unweathered drift, he appreciates the importance of ascertaining whether the alteration was accomplished by percolating ground waters acting along a more porous bed or by surface weathering during a period of time when the top of the lower drift was exposed. If the evidence shows that the alteration was accomplished by surficial weathering, the question then is how complete is the preserved record and how detailed an interglacial history can be read from it.

In the case of an incomplete record it is important to determine in what way and degree it is incomplete, in order that the available record may be properly evaluated. It is also equally important to determine, in the case of a complete record, the topographic and climatic conditions under which the weathering took place, the duration of the period of weathering, and whether or not topographic changes of consequence are reflected in the record.

Much was done by the early workers in determining what chemical changes had taken place in the weathered zones of the various

[1] *Illinois State Geological Survey Studies.*

glacial drift sheets, but not until Kay[1] pointed out that the gumbotil on the Kansan drift of southern Iowa was derived from normal glacial till by advanced chemical weathering under broad poorly drained flats did geologists give much attention to the topographic implications of weathered zones. This was a distinct step of progress. Recently the interpretation of weathered zones has been carried farther to include the recognition of an equally significant product resulting from weathering under well-drained conditions. It is also now recognized that all weathered zones on the glacial drift sheets of the Mississippi Valley states have fundamental and consistent subdivisions, each of which reflects the environment of weathering conditions. By recognizing these subdivisions it is possible to determine the completeness of the record more satisfactorily than has hitherto been possible and to determine what, if any, topographic changes occurred during the period of weathering.

PURPOSE OF THE PRESENT ARTICLE

This article summarizes the results of a detailed study of the weathered zones of drift-sheets, from the standpoint of their structures, their responses to different topographic situations, their stages of development with age, and their modifications under a new cycle of physiographic conditions.

For the benefit of the reader who may not be active in Pleistocene studies, the divisions of the North American glacial epoch are here given as follows:

GLACIAL AND INTERGLACIAL STAGES OF THE PLEISTOCENE EPOCH

Wisconsin glacial stage
  Peorian interglacial stage
Iowan glacial stage
  Sangamon interglacial stage
Illinoian glacial stage
  Yarmouth interglacial stage
Kansan glacial stage
  Aftonian interglacial stage
Nebraskan glacial stage (oldest known)

[1] G. F. Kay, "Gumbotil, a New Term in Pleistocene Geology" *Science*, New Series, Vol. XLIV (1916), pp. 637–38; G. F. Kay, and J. N. Pearce, "The Origin of Gumbotil," *Jour. Geol.*, Vol. XXVIII (1920), pp. 89–125.

CONCEPTION AND PERSONNEL OF THE PRESENT INVESTIGATION

In 1914, the late Dr. K. D. Glinka, director of the Agricultural Institute of Leningrad, recognized a twofold division of the soil above what he termed parent material and described how the characteristic features of these divisions persist or change consistently in response to the climate, regardless of the character of the parent-material.[1] Later Dr. C. F. Marbut, of the United States Department of Agriculture, visited Russia and brought back the germal thought behind Glinka's philosophy. Glinka assigned letters to his two divisions of the soil: the letter A to the eluvial surficial material from which, either by chemical or mechanical (probably both) means, more or less material has been removed; the letter B to the illuvial subzone into which the clayey material has been carried chemically or mechanically; and C to the parent-material beneath. His A includes the humus-charged silty material as well as any non-humus silty material that lies above the denser, more compact, and plastic B.

When Marbut in 1923 gave his series of splendid lectures at the University of Illinois on "The Great Soil Groups of the United States," the first-named author of this article conceived that a study of the characteristics of our modern soils and weathered zones, as they are developed on drift-sheets and loesses of different ages, under different topographic situations and vegetal coverings, should yield much information of value in interpreting more completely our fossil interglacial zones.

The study was soon undertaken by both authors, who were working on the Pleistocene deposits of Illinois, and after four years of study the present article is offered. During the study the authors have enjoyed the active collaboration of the state soil specialists of Illinois, Dr. R. S. Smith and Mr. E. A. Norton, who approached the problem from the standpoint of soil genesis and directed attention especially, and with great helpfulness, to the detailed characters of the soil and immediate subsoil materials. The authors, however, have been interested primarily in the geological aspects of the weath-

[1] D. Glinka, "Die Typen der Bodenbildung, ihre Klassifikation und geographische Verbreitung" (Berlin: Verlag Gebrüder Borntraeger, 1914).

ered zones taken as a whole, and assume responsibility for the geological classification, interpretations, and bearings here presented.

Although there are some climatic differences between northern and southern Illinois and some resultant differences in weathered zones on drift of the same age, these are not considered in the present discussion because they do not materially affect or alter the features mentioned.

SUBDIVISIONS OF THE WEATHERED ZONE

The weathered zone on the Illinoian drift-sheet in southern Illinois has reached a mature stage of development and is differentiated into clearly recognizable subdivisions, subdivisions that are much less clearly shown on the younger drift-sheets. Hence, the description of these subdivisions is largely based on the Illinoian weathered zone, although confirmed and extended by examinations of the weathered zones on the Kansan and Nebraskan drifts.

The weathered zone on the Illinoian and older drift-sheets, wherever preserved and exposed in a vertical section, is invariably divisible into four easily recognized horizons under all topographic situations except those in which erosion has cut away the upper ones (Fig. 1). These are as follows:

SUBDIVISIONS OF THE WEATHERED ZONE

Horizon 1: the surficial soil
Horizon 2: chemically decomposed till,* composed chiefly of alteration products and resistant constituents of the original till, and strikingly unlike the original till
Horizon 3: leached and oxidized till, otherwise but little altered
Horizon 4: oxidized till, but unleached and otherwise unaltered

* The term till is here used for unstratified glacial drift.

The unweathered till below may be referred to as horizon 5. The succession of horizons 1, 2, 3, and 4, as seen in an exposure, constitutes what is here designated as the "profile of weathering," which is a vertical section of the zone of weathering.

Horizon 1, the surficial soil, is silty and has characteristic structures, textures, and colors, for a given set of climatic, topographic, vegetative, and age factors, and, so far as the primary inorganic constituents are concerned, is probably the most thoroughly weathered of all the divisions. The authors are not yet ready to under-

take an adequate discussion of these characteristics under the various sets of conditions. The lower limit of horizon 1 is placed at the top of the vertical columnar structure of horizon 2, wherever this

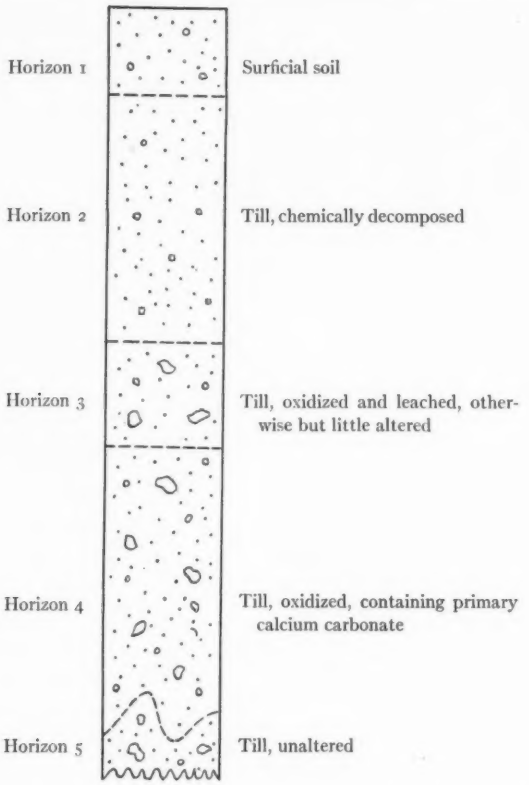


FIG. 1.—Generalized section showing maturely weathered zone in glacial till

structure is developed, but in some cases the columnar structure is absent, even in maturely weathered zones, and the division between 1 and 2 is indeterminate for practical purposes.

No attention is here given to abnormally thick deposits of surficial humus materials which accumulate in depressions by wash from

bordering slopes, to fossiliferous marls which form on lowlands, to peat-beds, or to other similarly accumulated soil material.

That there is some wind-blown dust or loess in almost every horizon 1 seems probable, but it is apparently very minor indeed in horizon 1 of the Illinoian drift, as shown by the remarkably consistent thickness of this horizon over broad areas, even to the very bluffs of the major valleys. Most of the loess was deposited more rapidly than leaching occurred, as shown by the calcareous zones, and then at the close of the loess-forming epochs weathering set in and changed their upper portions into weathered zones, giving consistent profiles within the superposed material. But in those areas where the mantle of loess is very thin, and particularly on the "crayfish flats" of southern Illinois, the loess may be not only much weathered but also modified in texture by the introduction of pebbles from the drift below by crayfish and other agencies. In the area mentioned a thin deposit, much weathered and apparently reworked, overlies the Illinoian weathered zone. If it is not a second-cycle weathered zone (see p. 49) modifying the upper part of the primary profile of the Illinoian drift, it is probably modified loess.

Horizon 2 is composed of the residue from, and some of the material produced by, oxidation, leaching, and advanced chemical decomposition. The pebbles are few and small, most of them less than $\frac{3}{4}$ inch in diameter, although occasionally a pebble $1\frac{1}{2}$ inches in diameter or larger may be found. They consist of chert, quartz, quartzite, jasper, and dense greenstone, and rarely of granite, diorite, gabbro, or other coarse-grained igneous rocks. Limestone pebbles and primary calcium carbonate are entirely lacking in the matrix.

The difference between this horizon and the unaltered till below is so great from the standpoint of lithology, texture, and chemical composition that one would scarcely suspect that the material was ever normal till, were it not for the transition downward into unmistakable till. Indeed, where horizon 2 rests on bedrock, there may be difficulty in finding igneous pebbles to prove that the deposit was originally till.

Horizon 3 is more characteristically till-like. It has suffered only oxidation and leaching and is the site of concentration of sec-

ondary iron oxide from above. The pebbles have a larger range in size than those in horizon 2, they are more dominantly of the arkosic type, and they include granite, diorite, gabbro, and other coarse-grained rocks which are firm except in the zone of transition from 2 to 3. But this horizon differs from the underlying horizon 4 in that it has no limestone pebbles or finely comminuted limestone flour, these materials having been dissolved. Rarely a remnant of a large limestone boulder is found, which, by reason of its size, has not been entirely leached away.

Horizon 4 has a normal content of primary calcium carbonate, and the limestone pebbles are firm except in the few inches of transition from 3, where they are etched and softened. It commonly contains concretions of calcium carbonate. The material in this horizon differs mainly from the material in horizon 5 in that it is oxidized. The oxidized zone grades downward into the unoxidized and unaltered parent-material.

ORIGIN OF THE HORIZONS

ORIGINAL COMPOSITION OF THE TILL

Only a general statement can be made here regarding the origin of the four horizons of weathering. Before weathering set in, the till of the drifts in the Mississippi Valley states was composed of a more or less compact or stiff, pebbly, calcareous clay, containing a greater or lesser number of boulders, according to the locality. The fine particles of the matrix as well as the pebbles and cobbles comprised a variety of material, sedimentary, igneous, and metamorphic, intimately mixed. The sedimentary material consisted chiefly of limestone, shale, sandstone, and chert; the igneous, of granite, diorite, gabbro, etc., and their porphyritic and fine grained equivalents; the metamorphic, of schist, gneiss, quartzite, argillite, vein quartz, jasper, greenstones, etc. The composition of the drift was thus calcareous and arkosic, including some very resistant types of rock; hence the chemical weathering that followed was necessarily selective.

WEATHERING AGENTS AND PROCESSES

With the change from a cold to a warm climate and the disappearance of the ice sheet, vegetation and animal life reinvaded the new drift area, and the organic, physical, and chemical weathering

processes set in, beginning at the surface and in the upper part and working downward. Surface and near-surface activity of roots, burrowing animals, wetting and drying, freezing and thawing, etc., as well as chemical processes, began promptly, and in time gave rise to horizon 1, of characteristic texture and structure.

Some of the surface and near-surface processes became ineffective with depth but chemical weathering proceeded, the different processes at different rates—*oxidation* and *hydration* the most rapidly; *leaching* of the limestone pebbles and calcareous matrix somewhat less rapidly; the *disassociation* or *decomposition* of the coarse-grained silicates still less rapidly; and, finally, for the oldest drifts, destruction of the more resistant fine-grained silicates and the slow solution of the cherts and quartzites. Owing to the different rates at which these four processes operate, the profile on the Illinoian and older drifts came in time to have the four horizons with thin transition zones between them.[1]

OXIDATION, HYDRATION, AND LEACHING

Ignoring the development of the surficial humus layer, the first zone to be formed was the oxidized and hydrated zone, the oxidation and hydration processes beginning virtually at the surface and working downward. The second zone was the leached zone. Leaching began simultaneously with oxidation but operated more slowly so that the leached zone proceeded downward as a second wave of alteration, following in the train of oxidation. There is considerable misunderstanding regarding the behavior of the leaching process in compact till. It is active only in the transition zone of from 1 to 4 inches that separates the leached zone above from the calcareous zone below. In this transition zone the limestone pebbles are etched and softened; above it the limestone pebbles and calcareous particles are gone; below it the limestone pebbles are intact, unetched, and firm, and the matrix has its normal content of primary calcium carbonate. Apparently ground water percolates very slowly through

[1] Since this article was written it has come to our attention that the different rates at which these several chemical processes have operated and the different depths to which they have progressed in the Kansan drift of Iowa and Minnesota were noted and described over twenty years ago by R. T. Chamberlin. These studies were not followed up and the data have remained unpublished in the original note books now in possession of the United States Geological Survey.

compact till and becomes saturated with lime carbonate within a few inches. Therefore, the leached zone deepens as this zone of active solution descends. Below the leached zone, the concretions and veins of lime carbonate found in many exposures probably represent the precipitation of lime carbonate from the descending waters, the amount precipitated being only that which the waters could not hold in solution.

In gravel the transition zone is apt to be somewhat thicker, depending on the size of its coarse aggregate, the amount and size of voids, and whether or not the position of the gravel permits free circulation of ground water. The inference is that ground water percolates farther in gravel, as a rule, than in till before it becomes saturated with lime carbonate. The anomaly of limestone boulders in an otherwise leached zone is due to the greater volume of calcium carbonate in its mass than in the same mass of till, its greater compactness, and the low ratio between the surface exposed and the volume of the mass.

CHEMICAL DECOMPOSITION OF THE SILICATES

Promptly upon the leaching of the calcium carbonate (and calcium magnesium carbonate), the carbonic acid and other acids of the downcoming ground water begin their attack upon the silicates. Thus the disassociation or chemical decomposition is a third wave of alteration that follows in the train of leaching. Commonly the zone of transition from the decomposed to the undecomposed coarse-grained silicates is no more than 6 or 8 inches thick. Above the transition zone there are few or no granites and diorites; in the transition zone the granites and diorites are soft, so much so as to be crushed in the hand, and below it they are firm. This wave of alteration lags behind the wave of leaching by from 1 to 2 feet in the Illinoian drift, and somewhat more in the Kansan drift. This would seem to indicate that chemical decomposition begins promptly at the surface upon the removal of the lime carbonate but that it proceeds more slowly than leaching, and the interval between the two increases with time.

The upper part of the zone of silicate decomposition is affected and modified, as noted above, by plant and animal organisms and

by the physical and chemical agencies and processes that operate at and just below the surface, thus creating the surficial soil layer or horizon 1.

CONCENTRATION OF IRON OXIDE

Just beneath the zone of silicate alteration there is a concentrate of iron oxide, in some places showing as a band or bands of rusty color, in others as a belt of concretions ranging in size from pellets to as large as 3 inches or more in diameter. These concretions have a considerable range of hardness, from soft clay having concentric circles, to hard clay ironstones. Distinction is to be made between these forms of iron-oxide concentration and the "pipe-stems" which develop around roots of vegetation and the pellets deposited by the action of soil bacteria.

The almost invariable occurrence of this "layer" of concentrated iron oxide at the base of the horizon of silicate alteration shows that it is constantly being dissolved and reprecipitated, migrating downward as the horizon of active alteration descends.

ILLUVIATION

Attention has been focused by many pedologists on the common presence of a plastic heavy subsoil zone in partially drained profiles which they account for by illuviation. This is not to be confused with the gumbotil which is largely the product of decomposition *in situ* in poorly drained areas. Wisconsin drift and the younger loesses commonly show an illuviated zone within slightly or partially decomposed silicate materials. Older drift, however, in partially drained profiles commonly shows an illuviated zone at the top of the maturely decomposed horizon 2, in which case it is the B horizon of the pedologists. It has also been found, however, *within* the body of horizon 2 and even *below* it. The authors, therefore, are led to the conclusion that illuviation is an *attendant* process rather than a *fundamental* one in the development of weathered zones, that it is an expression of certain physicochemical conditions which are likely to prevail near the surface but may also occur at lower levels. In so far as it appears commonly at the top of horizon 2, the designation B of the pedologists has its place in the present classification.

FACTORS DETERMINING THE RATE OF DEVELOPMENT OF SOIL PROFILES

Geographically the rates at which these changes take place are affected by the length of season when the ground is frost-free, the amount of water which enters the ground, the amount of water which is returned to the surface by capillarity, the rate at which the water passes downward, the temperature of the waters, the chemical composition of the material, the degree of comminution of the materials, the kind and character of the vegetation, the amount of carbon dioxide and other acid-making substances which the water obtains from the air and the humus-charged layer, the amount of oxygen lost by the water in passing through the humus and other deoxidizing material, the action of soil bacteria, and other agencies, processes, and conditions which cannot be discussed here.

The thickness of the zone of weathered materials also depends not only on the rate of weathering and the composition of the drift, especially its limestone content, but on the rate of removal of the calcium carbonate and also on the depth at which stagnant water occurs in the ground.

At most places the rate of weathering decreases with depth. The materials become more compact, some of the carbonic and other acids are neutralized in their alteration of silicates so that as time passes there is a lower and lower concentration of acid available for leaching at lower depths, and some of the oxygen of the waters is used in oxidizing the ferrous iron that is set free in the alteration of the silicates. The precipitation of lime carbonate in the calcareous zone, derived by leaching above, also adds that much more calcareous material to be leached again later.

When a new drift-sheet or a new loess deposit is superimposed and if it has sufficient thickness to cause a marked change in the chemical action of the descending waters, the development of the former zone of weathering stops and it becomes a "fossil" weathered zone, subject, however, to secondary changes.

FACTORS DETERMINING THE TYPE OF PROFILE DEVELOPED

TOPOGRAPHIC SITUATION

The foregoing characteristics hold, whatever the topographic situation, except on steep slopes where erosion proceeds as rapidly

as weathering, and possibly except beneath swamps and bogs where there has been little or no downward circulation of ground water. There are important ways, however, in which the factor of topographic situation exerts its influence on the *moisture conditions* of subsurface materials and leaves its characteristic impress on weathered zones that develop under these conditions, provided there has been adequate time.

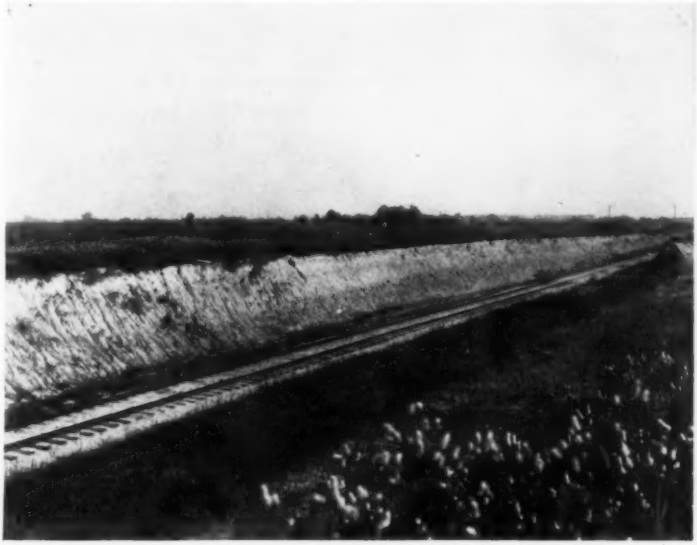


FIG. 2.—Flat, poorly drained land underlain by gumbotil developed on Illinoian drift, Marion County, Illinois (photo by MacClintock).

Broad, flat, poorly drained areas.—In the Illinoian drift area of southern and western Illinois, there are broad tracts of flat, poorly drained upland (Fig. 2). The profiles of weathering under these areas show an abnormally thick horizon 1; a gray to brownish gray, tenacious, plastic gumbotil in horizon 2, which when dry shows distinct vertical columnar structure; and a banded or splotched iron zone at the top of a thin horizon 3.

The gumbotil contains markedly fewer pebbles of much smaller average size and more pebbles of the resistant siliceous types than

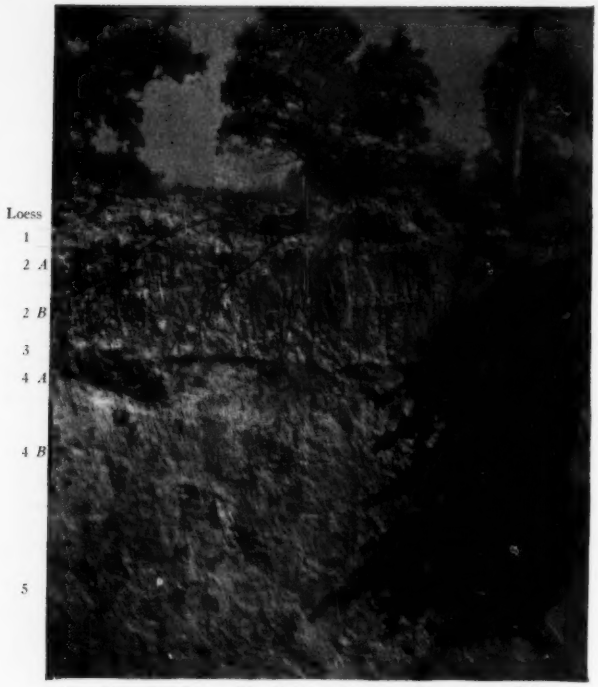
does the till of the lower horizons, and it is clearly a product of advanced weathering. Its topographic position on the highest broad

EXPOSURE SHOWING PROFILE DEVELOPED ON POORLY DRAINED ILLINOIAN DRIFT IN EFFINGHAM COUNTY, ILLINOIS

	Thickness	
	Feet	Inches
Soil and loess, containing a few scattered pebbles apparently introduced by organic agencies; upper 14 inches friable, the remainder compact and plastic; the lowest 9 inches may be a lower loess	2	10
Illinoian till:		
Horizon 1. Fossil soil:		
A. Soil, brownish black with red-brown spots, friable, non-plastic silt, containing sand and small pebbles	..	7
B. Silt, dirty gray, slightly more plastic than A, contains streaks of gray and reddish brown	..	12
Horizon 2. Gumbotil:		
A. Clay, sandy, pebbly, dark gray, streaked with rusty brown, plastic, compact, containing more pebbles than Horizon 1	1	8
B. Clay, very sandy, pebbly, light gray, plastic but not very compact; pebbles are distinctly larger near base, matrix splotched with yellowish brown and more so near base, some streaks of darker gray	2	6
Horizon 3. Till, leached and oxidized, otherwise but little altered:		
Till, sandy, pebbly, silty; non-calcareous, reddish brown, slightly iron-cemented, friable, non-plastic; includes both large and small veins of gray material, large veins more sandy than the general matrix, some faces black-coated	..	6
Horizon 4. Till, oxidized, containing primary calcium carbonate:		
A. Till, calcareous, brown, iron-cemented like horizon 3, some horizontal lenses of sand	1	8
B. Till, calcareous, oxidized, friable, compact, joint faces coated drab-gray, fresh surfaces grayish yellow	4	
Horizon 5. Unaltered till:		
Till, unweathered, blue-gray	6-8	

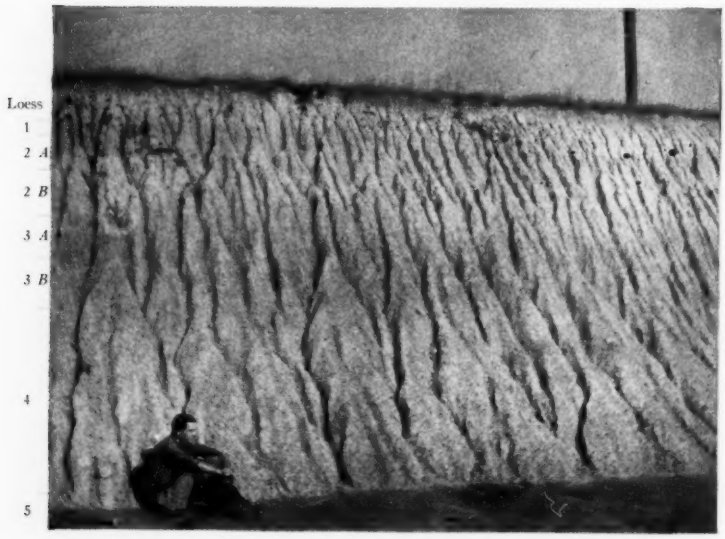
uplands and its gradation below into typical till shows that it was derived from till and not from slope-wash. The same profile has been developed beneath broad flat uplands on the Illinoian drift of southeastern Iowa and southwestern Ohio.

PLATE I



A. Gumbotil profile, 3½ miles southwest of Effingham, Effingham County, Ill. (Reprinted from Chamberlin and Salisbury's "College Geology," 1929.)

Horizon numbers are given along margin.



B. Silttil profile, near Helm, Marion County, Ill. (Reprinted from Chamberlin and Salisbury's "College Geology," 1929.)

Horizon numbers are given along margin.

Similarly the weathering profiles in the flat, tabular divides of the older Kansan drift of southern Iowa, where once existed broad stretches of poorly drained land, show even more impressively the same characteristics.

The Nebraskan drift, where exposed under the Kansan, commonly shows this same type of profile. Thus we can picture the topographic conditions of broad, flat, poorly drained plains which prevailed during Aftonian time when the Nebraskan drift was weathered to gumbotil, during Yarmouth time when the Kansan drift was similarly weathered, and during Sangamon time when the Illinoian gumbotil was formed.

A profile of weathering on poorly drained Illinoian drift may be seen beneath thin loess, $3\frac{1}{2}$ miles southwest of Effingham, Effingham County, in about the center of Sec. 6, T. 7 N., R. 6 E., at the lower (west) end and on the south side of a youthful, sharply incised gully. (See Plate I, *A*.) The section is shown on page 40.

A short distance east, perhaps 100 yards up the valley, the original material beneath the thin loess was sand and gravel; now it is completely changed to pebbly *gumbosand* with a transition below into gravelly sand and then dark till. This particular section illustrates admirably how sand and gravel under conditions of poor drainage may be changed into gumbosand, a product markedly different from the original material.

2. *Undulatory, well drained areas.*—Just as poor subsurface drainage conditions beneath broad, flat uplands are reflected in the development of gumbotil, so good subsurface drainage beneath undulatory areas leaves its characteristic profile of weathering. Profiles developed on gently sloping morainic swells or knolls (Fig. 3) on the Illinoian drift, although differing considerably, show characteristically the following: (*a*) a thinner horizon 1 than that developed in a poorly drained area; (*b*) no gumbotil in horizon 2, but rather a friable open-textured silt, brownish to buff in color and containing a few small, resistant, siliceous pebbles, for which the name *silttil*[1] seems appropriate, especially in contrast with the name

[1] Attention is here called to the pronunciation of *silttil* which is the same as if it were spelled silt-till; the hyphenated term silt-till, however, is not appropriate as the material is an alteration product from till that may originally have been clayey.

gumbotil; and (*c*) a concentration of iron, which may occur partly as concretions, at the top of a fairly thick horizon 3. The color of horizon 3 as developed in a well-drained area is generally reddish rather than yellowish or brownish as in a poorly drained area.

An excellent exposure of a profile developed under good drainage conditions, showing silttil beneath two thin loesses, occurs ½ mile south of Helm station on the new Illinois Central Railway cut-off,

FIG. 3.—Morainal topography of Illinoian age, 5½ miles southwest of Vandalia, Fayette County (photo by MacClintock).

in southeastern Marion County. (See Plate I, *B*.) The description is given on page 43.

It is conceivable that the comparatively stagnant water under flat areas permits the colloidal clayey products of chemical decomposition to be retained as such, whereas the more active subsurface drainage, as under knolls and ridges or near margins of valleys, either carries out much of the colloidal material, or the conditions favor the aggregation of the colloidal substances into silt particles, leaving a coarser, more open-textured material than the original till.

3. *Partially drained areas.*—Beneath partially drained areas the product of chemical decomposition is intermediate between the very plastic gumbotil and the friable, open-textured silttil; it contains enough clay and silt to make it semiplastic or semifriable and for it

the name *mesotil* is proposed, with the understanding that it applies to a much weathered *derivative* of till.

HELM EXPOSURE, SHOWING PROFILE DEVELOPED ON WELL-DRAINED ILLINOIAN DRIFT IN SOUTHWESTERN MARION COUNTY, ILLINOIS

	Thickness	
	Feet	Inches
Early Peorian loess:		
Soil, silty, gray	..	7
Silt, yellowish with reddish cast, friable	..	3
Silt, clayey, compact	1	..
Late Sangamon loess:		
Silt, clayey, heavy; upper part shows vertical columnar structure, the columns break into lumps which are coated with whitish material on the outside, brownish on the inside; the lower part is mottled brown and gray, compact and mostly massive	1	8
Illinoian till:		
Horizon 1. Fossil soil:		
Silt, sandy, humous-stained; contains an occasional pebble, mottled brown and gray	..	9
Horizon 2. Silttil:		
A. Silt, compact, sandy, slightly plastic, mottled brown and gray, contains few pebbles	2	0
B. Silt, sandy, friable, fairly compact, black iron-stain in lower part, contains few pebbles	2	0
Horizon 3. Till, leached and oxidized, otherwise but little altered:		
A. Iron-zone, leached, reddish, transected by veins of beidellite; fracture surfaces show iron-stain, pebbles are more numerous and larger than above	2	9
B. Till, brownish buff, leached, reddish and yellowish cast, friable; cellular where limestone pebbles have been leached	3	0
Horizon 4. Till, oxidized, containing primary calcium carbonate:		
Till, oxidized, calcareous; mottled gray and light yellowish buff, some transecting veins of beidellite	7–10	..
Horizon 5. Unaltered till:		
Till, unoxidized, calcareous, at bottom of cut	0–3	..

A medium-drained profile, approaching a well-drained profile, may be seen at the Oconee cut in Shelby County, along State High-

way No. 2, about 2 miles northeast of Oconee. The following description is of the south face of the deep road-cut west of Opossum Creek, 20 feet west of the center of the cut:

OCONEE EXPOSURE, SHOWING PROFILE DEVELOPED ON PARTIALLY DRAINED ILLINOIAN DRIFT IN SHELBY COUNTY, ILLINOIS

	Thickness Feet	Thickness Inches
Loess (probably Early Peorian):		
Soil, humus, medium-gray, containing occasional small pebbles and pellets of iron oxide up to $\frac{1}{8}$ inch in diameter	..	4
Silt, light gray to buff-gray	..	10
Clay, silty, compact, plastic, grayish buff to mottled gray and buff; columnar structure in upper part	1	8
Silt, yellowish	1	5
(There is some evidence in this area that the basal portion of the loess mantle is Late Sangamon in age.)		
Illinoian till:		
Horizon 1. Fossil soil:		
Silt, humus-stained, friable, brownish to grayish	1	0
Horizon 2. Mesotil:		
Silt, sandy, grayish buff, containing some small pebbles, mainly non-plastic but with an occasional semiplastic vertical streak; some black iron oxide stains in base, pebbles siliceous and of resistant types	3	3
Horizon 3. Till, leached and oxidized, otherwise but little altered:		
A. Till, reddish buff tone, iron-rich beidellite zone in upper part, vertical streaks of dark gray beidellite running through a silty sand matrix, mottled grayish buff and black; pebbles larger and more numerous than above, and an occasional ironstone concretion up to 2 or $2\frac{1}{2}$ inches in diameter; partly decomposed granite and diorite pebbles. This horizon produces a shoulder along the slope of the cut and checks on dry surface owing to cross-veins of beidellite	1	9
B. Till, leached, grayish buff, silicate pebbles mostly firm	2	3
Horizon 4. Till, oxidized, containing primary calcium carbonate:		
Till, oxidized, calcareous; transition zone of leaching at top is limited to about 3 inches below which limestone pebbles are firm and unetched	10+	..

The variety of topographic forms which control the moisture conditions of the subsoil, and the transitions from one to another, cause the development of soil profiles that represent all gradations between those characteristic of poorly drained and those characteristic of well-drained areas. For example, an exposure 1 mile east of Effingham, Effingham County, along a road-cut through the upper part of the east valley wall of Salt Creek, shows an intermediate profile more closely related to the poorly drained profile than is the Oconee exposure just described. Horizon 2 of the profile of weathering on the drift, beneath the overlying modified loess, contains more clay than horizon 2 of the Oconee exposure, and yet is not a true gumbotil.

Obviously, the majority of profiles seen in an undulatory area are intermediate between the two extreme types, namely, the gumbotil and silttil profiles, and might be classed as medium-drained or *mesotil* profiles. They show commonly a light silty horizon 1 and a more or less heavy horizon 2, depending on whether the particular profile studied was produced under conditions approaching poor drainage or good drainage (Fig. 4).

The thesis of the present article embodies the modern concept that the weathered zone is a dynamic whole which is continually subject to changes under environmental influences and for that reason shows alteration, gradation, and evolution from time to time as well as from place to place.

VEGETATION

1. Synchronous with the other factors of soil genesis, vegetation plays a rôle. Luxuriant grasses on prairies commonly give rise to a horizon 1 highly charged with black humus material, whereas a forest cover in the same climatic zone on flat tracts results in light gray material below a thin blanket of forest litter, becoming yellowish gray on undulatory tracts.

2. Vegetation on a gentle slope, in a moist climate, may become so luxuriant as to cause medium or poor drainage, where without the heavy plant cover a well-drained profile might develop.

3. Likewise, poor subsurface drainage conditions on a gentle

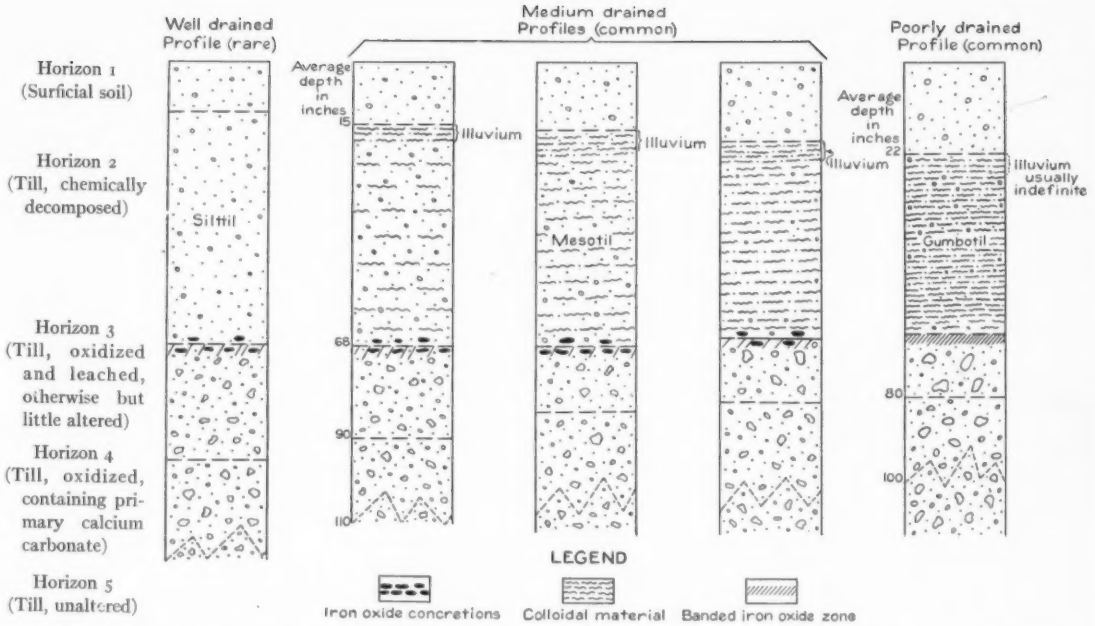


FIG. 4.—Diagrammatic summary of the gradational series of weathered profiles on the Illinoian drift in southern Illinois, from the well-drained to the poorly drained types (thicknesses given are averages from computations made by courtesy of R. S. Smith and E. A. Norton, Illinois State Soil Survey).

slope may prevail while there is sufficient lime near the surface to support a luxuriant vegetation, but when the lime becomes deeply leached and the soil therefore becomes infertile the vegetation becomes light and the subsurface drainage better. There will be a consequent change in the weathered profile, the character of which will depend upon the length of time that has elapsed since the change took place.

PERMEABILITY OF THE PARENT OR SUBJACENT MATERIAL

1. Where the parent-material was originally somewhat impervious to ground water, weathering has proceeded more slowly and the profile developed is not so deep and may not be so well drained as the type found in similar topographic positions on the same drift where all the material is easily penetrated by percolating waters. Good examples are seen on the Paxton and Marseilles moraines where profiles developed in morainal belts of heavy clayey material approach the type characteristic of poor drainage conditions.

2. Impervious subjacent material affects the profiles formed in thin superjacent material. Thus the profile developed in relatively thin loess lying on gumbotil, other conditions being the same, shows a poorer drainage during its development than where the loess is underlain by porous material.

COMPARATIVE DEVELOPMENT OF WEATHERED ZONES ON THE VARIOUS DRIFT-SHEETS OF THE MIDDLE WEST STATES

The length of time that a drift-sheet has been subjected to weathering is an important factor in the stage of development of its weathered profiles.

The Wisconsin drift shows a shallow, youthful, less obviously differentiated profile of weathering than that of the Illinoian drift. That portion of the Wisconsin profile which corresponds to horizons 1, 2, and 3 of the Illinoian and older drift-sheets is only from $2\frac{1}{2}$ to 4 feet thick, as compared with a much greater thickness for the older drifts. Indeed, horizon 2 of the Wisconsin drift in many places is not yet sufficiently deep to be easily differentiated from horizon 1.

In the Iowan drift area, the topography is mainly undulatory and for the most part has well drained or partly drained profiles of weathering. In some localities poor drainage conditions prevail on

the uplands, but in any case the weathered zones show a youthful stage of development but slightly more advanced than that of the weathered zone of the Wisconsin drift.

The Kansan weathered zone shows the same divisions of the weathered profile as does the Illinoian, but thicker and in a still more advanced stage of development. Most of the described weathered zones on the Kansan drift exhibit gumbotil profiles. The gumbotil (horizon 2) is more plastic and the pebbles are fewer and smaller than in horizon 2 of the Illinoian drift. With the conception of weathering profiles in mind, further study of the Kansan drift area may reveal belts of former morainal topography, now greatly subdued and eroded, but possessing the silttil profile, that is, reflecting original good drainage conditions.

The buried gumbotil profile of the Nebraskan drift approaches that of the Kansan in its stage of development.

AREAL AND CORRELATIVE IMPORTANCE OF THE POORLY DRAINED, THE MEDIUM-DRAINED, AND THE WELL-DRAINED WEATHERED PROFILES

In central, south-central, and western Illinois, southern, eastern, and western Iowa, and northern Missouri, there are broad, flat, tabular divides where the poorly drained profile prevails. Indeed, it was in southern Iowa that the occurrence of gumbotil was first recognized by McGee[1] and later worked out and its importance emphasized by Kay.[2]

On the other hand there are large rolling areas, as in southern Illinois, where the original thickness of the drift was not sufficient to fill the bedrock valleys, and where belts of morainal topography occur, in which the medium-drained profile prevails, with an occasional local occurrence of the well-drained profile. In northwestern Illinois the same situation holds; also in the Iowan drift area of northeastern Iowa, the older drift area of the northeast corner of Iowa, and the thin drift area of northeastern Kansas. Doubtless there are similar conditions of alternating flat and undulatory areas

[1] W. J. McGee, "The Pleistocene History of Northeastern Iowa," *U.S. Geol. Survey, 11th Ann. Report, Part I* (1891), p. 509.

[2] G. F. Kay, and J. N. Pearce, "The Origin of Gumbotil," *Jour. Geol.*, Vol. XXVIII, No. 2 (1920), pp. 89–125.

in Wisconsin, Minnesota, North Dakota, Montana, South Dakota, and Nebraska. In the western part of the Mississippi basin, however, the smaller amount of rainfall is probably reflected in the development of profiles of weathering quite different from those discussed in the present article. But within the region whose climate is closely similar to that of Illinois, it is important for the glacial geologist and the pedologist to bear in mind the characteristic environmental responses of the weathering processes and the consequent profiles of weathering herein described.

In the middle states, and particularly in Illinois, it has been found that the average thickness of horizon 2 of the silttil and mesotil profiles is slightly greater than that of the gumbotil profile. Apparently the somewhat greater run-off in the one case is more than balanced by the slow percolation of water in the other. At any rate, the important fact is that in areas of the same climate, horizon 2 of the mesotil profiles, where erosion is not excessive, has essentially the same value in correlating or differentiating drift-sheets as horizon 2 of the gumbotil profile.

SECOND-CYCLE PROFILES

After a long period of weathering under poor drainage conditions, resulting in the development of a gumbotil profile, erosion may work headward into the area and bring about a change to better drainage conditions, both surface and subsurface. In such an event the profile is changed, first in horizon 1 and then in horizon 2. The colloidal material in horizon 2 is either removed and carried away by ground water or is precipitated to form silt particles. Beginning at the top and working downward, the change becomes more marked and deeper out near the slope where the new conditions are first felt, and is less evident back under the upland (Figs. 5*a* and 5*b*). If the change is not complete (and in many cases it is not), there will be a second-cycle mesotil or silttil profile transecting the old horizon 2; the buff-colored open-textured silttil of the new, resembling pebbly loesslike silt, resting upon a remnant of gumbotil, and with an iron pellet zone separating the two.

In Figures 5*a* and 5*b*, is recorded the following history: first, there developed the glacial climate of the Illinoian stage which re-

sulted eventually in ice invasion and deposition of the till; second, the climate moderated, the ice receded, and weathering proceeded

FIG. 5*a*.—Exposure showing a two-cycle weathered profile on glacial drift beneath loess, resulting from dissection after development of the gumbotil and before deposition of the loess. One mile east of Trenton, Illinois, east-central part of Sec. 21, T. 2 N., R. 5 W., Clinton County (photo by MacClintock).

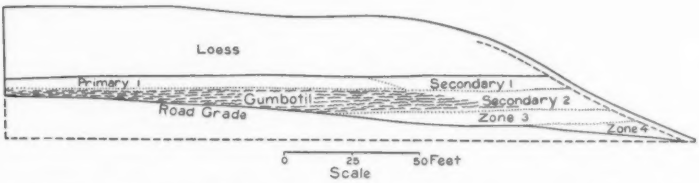


FIG. 5*b*.—Diagrammatic sketch of exposure (Fig. 5*a*), showing the character of the material, the relations of the secondary profile to the primary, and the relations of both to the loess.

under poor drainage conditions for a long period of time, producing the gumbotil profile; third, erosion finally worked headward, chang-

ing the conditions of weathering from those of poor drainage to those of good drainage, and adjacent to the valley a secondary profile was developed upon the primary profile; fourth, the development of the secondary profile was brought to a close by an episode

BIG CREEK EXPOSURE OF INTERGLACIAL SOIL, S. CEN. NW ¼ SEC. 2, T. 11 N., R. 12 W., CLARK COUNTY, ILLINOIS

	Thickness	
	Feet	Inches
Illinoian till:		
Till, leached	7	..
Till, calcareous, oxidized, dark buff-colored	18	..
Till, calcareous, dense, blue-gray, containing wood and gastropod shells in lower part	25	..
Pre-Illinoian till:		
Secondary profile:		
Horizon 1:		
Moss or grass	..	½
Soil, calcareous, fossiliferous	..	2
Silt, light, powdery, fluffy, reddish brown; horizontal fracture tendency; leached	1	..
Horizon 2:		
Mesotil, dense, compact, leached, conchoidal fracture with columnar tendency; contains few scattered siliceous pebbles	3	6
Primary profile:		
Horizon 2:		
Gumbotil, bluish gray to brownish	2	..
Horizon 3:		
Subgumbotil, iron-stained and in places iron-cemented; leached	1	6
Horizon 4:		
Till, calcareous, drab-brown, dense, hard	4	..
Horizon 5:		
Till, calcareous, blue-gray, dense	18	..
(Covered by slump)	10	..

of loess deposition. The negligible quantity of loess on the valley slopes in this case is clearly due either to removal almost as rapidly as it was deposited or to its subsequent removal.

In some places an earlier till, having both a primary and a secondary profile, is overlain by another drift rather than by loess, as,

for example, the Nebraskan drift overlain by the Kansan drift. Where the glacialist is so fortunate as to find the top soil of the buried drift preserved, he has before him a complete interglacial record, illuminated by the recognition of the two profiles of weathering. The Big Creek section[1] in Clark County, is illustrative.

The recognition of the mesotil or the silttil profile, whether of a first or second cycle, is important in drawing the boundary between

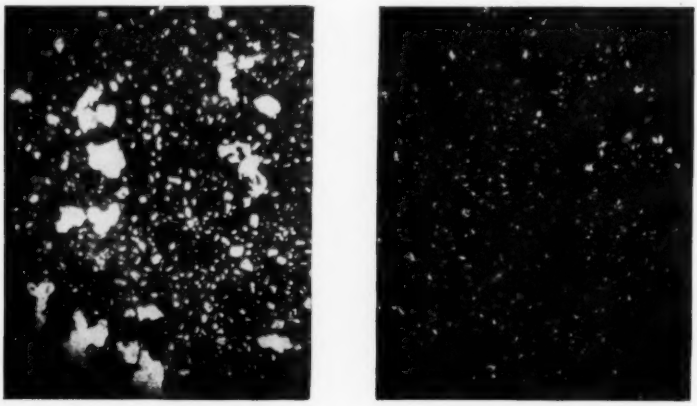


FIG. 6.—Photomicrograph of (*A*) silttil and (*B*) loess. Crossed nicols, magnified 30 times (photo by Leggette).

loess and till. In times past it has been common to consider any loesslike silt containing a few scattered pebbles as the basal part of loess, on the assumption that the pebbles were introduced by secondary agencies from the till below during the opening phase of the loess deposition. This is of course possible, and it is pertinent, therefore, to look for differentiating criteria. Under the microscope true loess looks remarkably uniform in size and shape of particles, whereas silttil is exceedingly irregular and heterogeneous. The contrast is well shown in Figure 6.

If the exposure is situated at the brow of a slope or just back

[1] Paul MacClintock, "Recent Discoveries of Pre-Illinoian Drift in Southern Illinois," *Illinois State Geol. Survey, Report Inv. No. 19* (1929).

from it, it is likely to contain a trace of an old surficial soil at the very top of the loesslike silt which carries the scattered pebbles. The loesslike silt in such a case is the silttil of a well-drained profile of weathering.

On a steep slope, however, where a pebble line separates till from pebbly loesslike material, the loesslike material is due to slope-wash, either from the partly drained profile higher up on the slope or from the first loessial covering.

SUMMARY

The study of weathered zones has revealed that there is a response to the physiographic and vegetative environment, as well as to the climatic and subsurface drainage conditions; that the ultimate product of weathering, as represented in horizons 1 and 2, is radically different in chemical composition, structure, texture, and consistency from the parent-material; that the *gumbotil* of the poorly drained profile has its counterpart in the *mesotil* of the medium-drained profile and in the *silttil* of the well-drained profile; that the weathered zone passes through orderly stages of development; and that with a change from physiographic conditions of poor drainage to those of partial or good drainage, there is instituted a second cycle of profile development, that is, eluviation of the poorly drained gumbotil profile to make the medium-drained mesotil profile or the well-drained silttil profile. It therefore seems possible to interpret with considerable confidence the physiographic history of interglacial times.

This conception of weathered zones relates them to their physiographic, climatic, and vegetational setting; provides the framework for a comprehensive study of weathered zones and their profiles; provides criteria for drawing more precise boundaries between weathered till and superjacent loess; illuminates interglacial history; stresses the importance of environmental factors as well as climatic factors in the classification of soils; promises a new line of attack for the study of the evolution of plants; and stimulates another angle of approach to the study of the underclays of coals and of unconformities between certain types of materials in our bedrock and unconsolidated formations.

AN ALNÖITE PIPE, ITS CONTACT PHENOMENA, AND ORE DEPOSITION NEAR AVON, MISSOURI

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The Johns Hopkins University

INTRODUCTION

One mile north of Avon and 11 miles east of Farmington, on the A. W. Vogt farm, near the east center of SE. $\frac{1}{4}$, NE. $\frac{1}{4}$, Sec. 2, T. 35 N., R. 7 E., is a small igneous intrusion in the Bonneterre dolomite around the periphery of which sulphide ore has been deposited. The intrusion is shown on the Ste Genevieve County geologic map issued by the Missouri Bureau of Geology and Mines.

The locality is of especial interest because of the unusual character of the igneous rock and its contact phenomena, and because it is briefly described by Spurr[1] and interpreted by him as evidence that the southeast Missouri lead deposits constitute an ore-magmatic district.

DESCRIPTION OF INTRUSION

Spurr refers to the intrusion as a peridotite pipe some 200 feet in diameter. A fuller description of the intrusion is given by Ball.[2] The outcrop is slightly elliptical in shape with the longer axis 200 feet long. He says a diamond drill hole slightly south of the center of the mass with a depth of 305 feet was entirely in igneous rock, whereas two vertical holes within 25 feet of the north and west boundary remained entirely in sedimentary rock. It appears that the intrusion is a pipelike mass that forced its way up through the Bonneterre dolomite.

The dolomite around the intrusion was much shattered. Fragments were caught up in the igneous rock and the shattered dolomite was penetrated in a most intricate manner by it. The dolomite was in part assimilated and in part contact metamorphosed. Ball in

[1] J. E. Spurr, "The Southeast Missouri Ore-Magmatic District," *Engineering and Mining Journal*, Vol. CXXII (1926), p. 970.

[2] S. H. Ball, "A Genetically Interesting Southeast Missouri Lead-Zinc Deposit." Manuscript kindly placed at our disposal.

describing the zone of metamorphosed limestone states it has a width of about 20 feet.

AUGITE-FREE ALNÖITE

The rock is a dark greenish gray porphyry with large phenocrysts of blackish green serpentine, small tufts of golden brown mica, and a dull greenish gray aphanitic groundmass. Locally the serpentine phenocrysts compose nearly half of the rock and they range in size up to a maximum of 10 mm. The tufts of mica are more abundant than appears on casual examination, owing to their smaller size, but they constitute a much smaller percentage of the rock than does the serpentine.

In this section (Fig. 1) the rock is seen to consist mainly of olivine, now largely altered to serpentine, phlogopite, melilite, and accessory apatite, magnetite, chromite, and perofskite. Secondary carbonate, probably largely dolomite, occurs in patches and minute fractures.

Olivine was decidedly the most abundant constituent of the original rock. It occurred in the large phenocrysts and in the groundmass. It has been completely serpentinized in much of the rock, but in places it still occurs abundantly as remnants in the serpentine (Fig. 1). The phenocrysts were subhedral to rounded in outline. It is clear and colorless and has lower double refraction than common olivine. The indices of refraction fall between 1.665 and 1.695 and the optic angle is large, $2V = 90\pm$. The low double refraction indicates an olivine approaching monticellite rather than forsterite in composition.

Serpentine is now the most abundant mineral of the rock. It has fibrous texture, is very low in double refraction, and has positive elongation. Its index of refraction is $1.565\pm$. These properties correspond to the variety antigorite. It occurs both in the phenocrysts and in the groundmass.

Phlogopite occurs in folia throughout the rock but most abundantly in the groundmass. Occasional flakes are enclosed in the serpentine phenocrysts. There is also a more or less continuous border of mica flakes around the serpentine phenocrysts, often penetrating them with irregular replacement boundaries (Fig. 1). Less commonly flakes of phlogopite seem to be replaced by serpentine.

The mica has a pale red-brown or salmon color and is moderately pleochroic. Its index of refraction in the basal plane is 1.585 ± 0.005 and it is negative with optical angle almost zero. The absorption

FIG. 1.—Thin section of alnöite showing large phenocrysts of serpentine in turbid groundmass consisting largely of melilite. The center of the large phenocryst is a remnant of unaltered olivine. The black streaks in the phenocryst consist of secondary magnetite. The serpentine phenocrysts are bordered by phlogopite which penetrates them with replacement boundaries. The groundmass includes considerable serpentine and opaque ore minerals. ×20.

is abnormal, $x > y = z$. Similar abnormal absorption in phlogopite in a Montana alnöite is described by Ross[1] and has been noted by others in mica peridotites.

[1] C. S. Ross, "Nephelite-Hauynite Alnöite from Winnett, Montana," *Amer. Jour. Sci.*, Vol. XI (1926), p. 219.

Melilite is almost confined to the groundmass in which it swarms as minute turbid yellow anhedral grains constituting often more than half of the groundmass. The grains are nearly isotropic. Occasionally larger, well-developed quadratic crystals are embedded in serpentine of the phenocrysts. The largest of these are less than 0.5 mm. in size. They are so nearly isotropic that they show only the slightest birefringence with the gypsum plate. The near isotropism is characteristic of natural melilites and is indicative of a composition intermediate between akermanite and gehlenite. The indices of refraction are about 1.64. Rectangular grains show the characteristic suture and a few grains show a speckled pattern on the base indicating a tendency to the development of the peg structure.

Apatite in the usual hexagonal prisms is abundant. Irregular grains of *magnetite* are also abundant. Scattered grains of *chromite* which show a brown color in strong transmitted light tend to a diamond-shaped cross-section. The groundmass swarms with minute crystals of *perovskite* in modified cubes.

The rock has been so thoroughly serpentinized that it is impossible to secure a specimen of the unaltered rock for chemical analysis. A sample of the serpentinized rock very kindly analyzed for us by Penniman and Browne of Baltimore showed the following composition.

SiO_2	34.63%
Al_2O_3	13.83
Fe_2O_3	1.76
FeO	3.60
MgO	22.40
CaO	12.26
Na_2O	trace
K_2O	1.14
H_2O+	8.60
H_2O-	0.10
CO_2	0.37
TiO_2	0.16
P_2O_5	0.51
MnO	0.19
Cr_2O_3	0.21
Cl	0.052
Fl	0.16
	99.97+

The analysis indicates a rock of the following approximate mineralogic composition:

Serpentine	60.0%
Melilite	20.0
Phlogopite	9.5
Olivine	6.0
Magnetite	2.0
Chromite	0.3
Apatite	1.0
Perovskite	0.2
Calcite	1.0

The rock differs from the usual alnöite in the absence of augite and the occurrence of a phlogopitic mica instead of biotite. Phlogopite, however, seems not uncommonly to be the mica in alnöites. The fresh rock had as its three most abundant constituents olivine, melilite, and a dark mica, three of the characteristic constituents of alnöite. The rock may be appropriately called augite-free alnöite.

THE ALNÖITE-DOLOMITE CONTACT

The intimate relationship of the alnöite and the dolomite has been mentioned. Abundant fragments of dolomite in the rock of the pipe itself show all degrees of assimilation by the magma and indicate that its composition was modified by the addition of lime and magnesia from that source. The dolomite breccia forming the walls of the pipe has been invaded by the magma in so intricate a manner that there is every gradation from alnöite enclosing fragments of dolomite to shattered dolomite penetrated by veins and stringers of igneous material which fade away into the dolomite as dark streaks with indefinite hazy boundaries (Fig. 2). The dolomite has been transformed into a dense, fine-grained rock ranging in color from nearly white to dark gray. Some of the rock is of a uniform gray color, but much of it is light gray with poorly defined blotches and streaks of darker gray. Many of the streaks are parallel to and branching from the stringers of magmatic material that traverse the dolomite. The recrystallization and darkening of the dolomite are clearly the result of contact metamorphism (Fig. 2). The unmetamorphosed dolomite is a coarser-grained, glistening, grayish white dolomite.

Ordinary pyrometasomatism with the formation of contact silicates has occurred to a very limited extent only. A few small fragments of dolomite have been almost completely transformed to xonotlite. They are now a dense white tough substance that under the microscope is seen to consist of minute granular aggregates and radiating fibers of a mineral having about the double refraction of quartz and indices of refraction 1.584 ± 0.004. The fibers have positive elongation and the optic angle is practically zero. The mineral

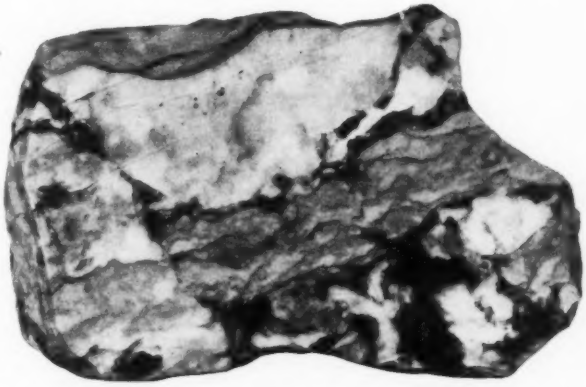

FIG. 2.—Metamorphosed dolomite breccia forming walls of pipe. The wide black areas represent filling of breccia by predominantly igneous matter. This fades away transitionally into the hazy gray veinlets in which igneous matter plays a subordinate rôle. The dolomite has been transformed into a dense mottled gray rock. Though the rock is primarily a breccia, the boundaries of the dolomite fragments indicate considerable assimilation and replacement has taken place. Natural size.

decomposes in hydrochloric acid with the separation of silica. These properties identify the mineral as xonotlite ($5CaO \cdot SiO_2 \cdot H_2O$). Traversing the xonotlite are a few acicular prismatic crystals that are completely altered to carbonate and no longer identifiable which may have been tremolite. Throughout the xonotlite, and especially abundant around the periphery of the acicular crystals, are swarms of minute opaque spherules that are snowy white in reflected light. Their appearance suggests leucoxene except for the spherical form and their great abundance. They are too minute to be separated for chemical tests. Between the xonotlite mass and the alnöite is a

transition zone less than 1 cm. wide consisting of diopsidic pyroxene, phlogopite, and xonotlite. A few small brown garnets also occur. The pyroxene is in clear, light green, prismatic crystals with a maximum length of $1\frac{1}{2}$ mm. and width of $\frac{1}{2}$ mm. In thin section it has a pale greenish tinge and barely noticeable pleochroism. The optical character is positive with moderate axial angle. The extinction angle against perfect prismatic cleavage is 45°. There is weak zoning but no twinning.

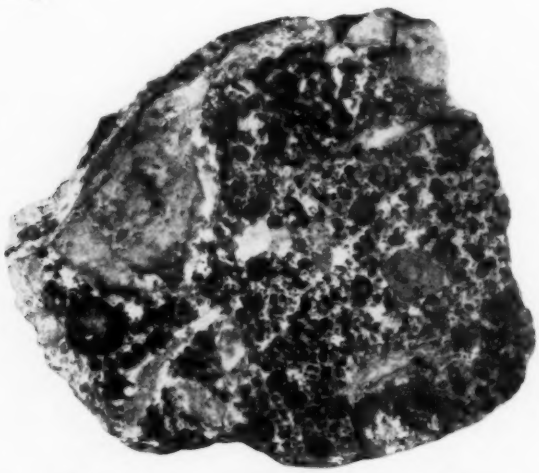

FIG. 3.—Spherules of alnöite and remnants of Bonneterre dolomite, which are recrystallized and replaced in part by magmatic solutions, imbedded in a matrix of carbonates. Natural size.

The more common contact relations are those illustrated in Figures 2 and 3. As the magma penetrated the dolomite breccia it assimilated much dolomite and broke up into spherules which are now embedded in a carbonate matrix. The contact rock consists of fragments of dolomite in all stages of assimilation cemented by the aggregate of alnöite spherules in a carbonate matrix (Fig. 3). Figures 4, 5, and 6 illustrate various stages and phases of this peculiar and unusual rock. It appears that when the alnöite magma was forced into the shattered zone of the neck of the pipe, it disintegrated to spherules consisting of one or more olivine or serpentine phenocrysts

surrounded by a zone of the still liquid groundmass. The spherules seem to have been cushioned and contained in a much more mobile medium that probably consisted of the gaseous and volatile constituents of the magma and the carbon dioxide that was being expelled

FIG. 4.—Alnöite with miarolitic-like cavities. The olivine phenocrysts have been changed to serpentine and carbonate. The miarolitic cavities are filled with carbonate, and the large central cavity is rimmed with magnetite intercrystallized with the carbonate. The slide shows a slight tendency of the igneous rock to break down into spherules. ×20.

from the dolomite assimilated by the magma. In some places there is only an incipient development of the spherules and miarolitic-like cavities formed which are filled with carbonate and in some instances rimmed with magnetite (Fig. 4). With an extension of the branches of the cavities, the rock tends to break down into spherules. A more

advanced stage of this disintegration is shown in Figure 5, in which the miarolitic areas have coalesced into a more continuous matrix of carbonate which separates the individual spherules. The complete breaking up of the alnöite magma into spherules is illustrated by

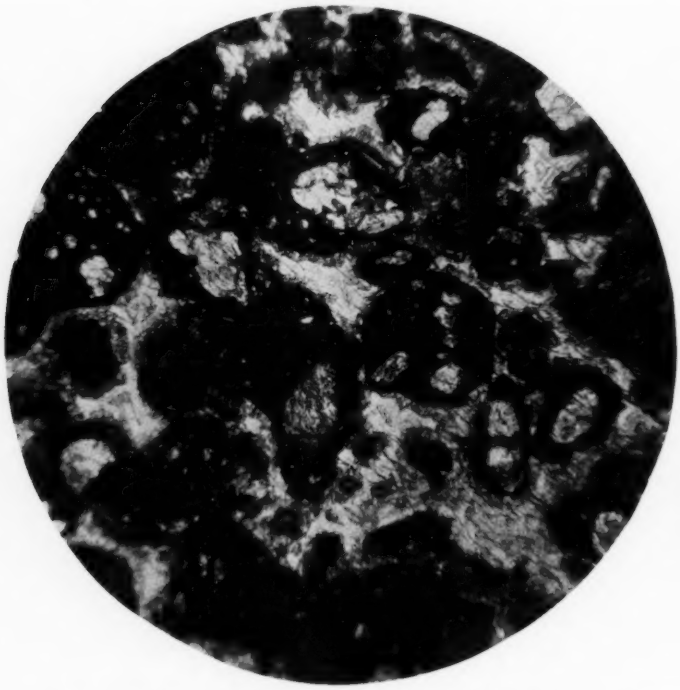

FIG. 5.—Alnöite breaking down into spherules the interstices between which are filled with carbonate. The spherules consist of one or more phenocrysts surrounded by groundmass identical with that of the alnöite from the plug itself. ×20.

Figures 3 and 6. Figure 6 is a microphotograph of a portion of Figure 3. At this stage the igneous spherules are for the most part no longer in contact, but the magma of the spherules has still retained its identity.

The material just described grades over into the darkened dolo-

mite of Figure 2 and the dolomite remnants seen in Figure 3. Under the microscope the dark streaks are seen to consist of faintly developed whorls of serpentinic and chloritic laths similar to those in the groundmass of the alnöite but without the phenocrysts of the spher-

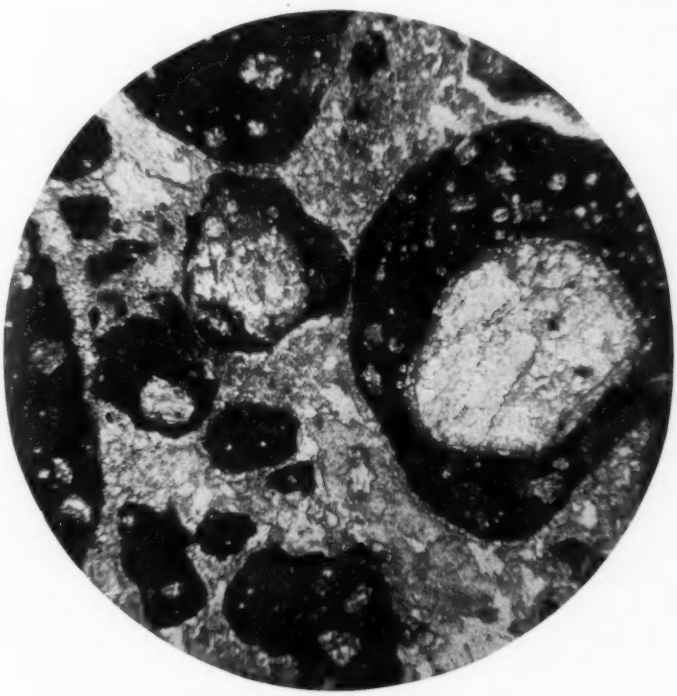

FIG. 6.—Alnöite spherules embedded in carbonate matrix. This slide represents complete breaking up of alnöite magma into droplets. ×20.

ules. They have penetrated the dolomite by replacement along minute cracks and even independently of any fracturing.

These unusual textures seem to have been caused by a great concentration of the volatile constituents of the magma and of the carbon dioxide liberated by the assimilation of large quantities of dolomite. Under this heavy gas pressure magma was blown with

great violence into the shattered dolomite of the walls of the pipe. The larger openings of the breccia were filled with drops of alnöitic magma cushioned against each other by the volatiles and the matter they carried in solution. The rapid cooling that followed this violent injection prevented the re-establishment of equilibrium so that the droplets of magma solidified as such and the interstices between them were filled with carbonate deposited from the gaseous phase. The more tenuous and mobile portions of the magmatic residues penetrated into openings still smaller and into the rock itself recrystallizing the dolomite and replacing it with magmatic constituents which they carried in solution.

The unusual textural features of the contact breccia are probably causally related to the mechanism of the alnöite intrusion. It appears that the alnöite pipe was analogous to a diatreme, the magma having made its way into the Bonneterre dolomite with explosive violence. The sudden escape of gas into the brecciated dolomite blew out with it drops of magma which solidified quickly in a medium of dissociated carbonates. With decreasing temperature and pressure, carbonates reformed as the matrix of the igneous spherules.

ORE DEPOSITION

Later than the igneous intrusion and metamorphism of the dolomite, calcite, siderite, sphalerite, galena, chalcopyrite, marcasite, and pyrite were deposited in the dolomite at the periphery of the igneous plug. These minerals occur in both the glistening crystalline dolomite, and in the dense gray stony rock derived from it by contact metamorphism. They are introduced along fractures as filling of the fractures and by replacement of the walls. Some irregular, wavy stringers branching off from veinlets may be due entirely to replacement.

The vein calcite is coarsely crystallized and twinned. It is transparent to white in color and much of it has a pinkish tone. The siderite is more finely crystallized, often as small rhombs. The sphalerite has a light yellow or cinnamon color. In many cases a border of small sphalerite grains is imbedded in the dolomite along its contact with coarse calcite. Sphalerite and galena were deposited at about the same time, since veinlets of sphalerite traverse galena, and

veinlets of galena traverse sphalerite. On the whole, however, galena is later than sphalerite. Pyrite often shows cubic crystals and the marcasite is recognized by its radiated form.

Ball[1] states that calcite and galena are most abundant and that the other minerals in order of decreasing abundance are sphalerite, marcasite, chalcopyrite, pyrite, and smoky quartz. He says there are well-developed crystals of chalcopyrite, galena, marcasite, and smoky quartz. To this list may be added sphalerite which occurs in small well-developed crystals imbedded in the coarse calcite. He says that galena occurs in cubes up to 1 inch in diameter.

There is no evidence of genetic relationship between this mineralization and the igneous intrusion. The alteration of the limestone caused by the igneous intrusion is clearly earlier than the mineralization. The minerals were introduced into the contact-metamorphosed limestone in exactly the same way in which they were introduced into the unaltered Bonneterre rock. The location of the mineralization at the periphery of the igneous plug appears to be due solely to the fact that fractures in the limestone afforded there channels for the circulation of the mineralizing solutions irrespective of what their origin may have been. The close proximity of the igneous rock with its contact zone and the mineralization is purely accidental and cannot be used as an argument for or against the magmatic origin of the lead deposits of southeastern Missouri. Whatever may have been their origin was also the origin of this mineralization.

SUMMARY

Near Avon, Missouri, a pipe of augite-free alnöite has intruded the Bonneterre dolomite with explosive violence and the assimilation of much dolomite. A sudden release of high gas pressure in the magma blew drops of magma into the shattered walls of the pipe. These drops solidified quickly and were imbedded in carbonates deposited by the magmatic emanations. The more tenuous and mobile magmatic constituents penetrated the dolomite, recrystallized it, and deposited additional magmatic matter. Later solutions entered fractures in the dolomite at the periphery of the pipe and deposited

[1] *Loc. cit.*

the same ore and gangue minerals that occur in the southeastern Missouri disseminated lead deposits. There is no evidence to indicate that the igneous pipe had any relation to this mineralization other than that its locus provided channels of circulation for the mineralizing solutions.

The authors express their appreciation of the assistance of Dr. S. H. Ball, Dr. Clarence S. Ross, and Dr. N. L. Bowen in the study of this interesting locality.

EVIDENCES FOR A RELOCATION OF THE DRIFT BORDER IN EASTERN KANSAS

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ABSTRACT

Field investigations carried on in the region of the attenuated drift border in northeastern Kansas indicate that an ice sheet extended beyond the limits of the previously mapped glacial border. The evidences cited are the presence beyond the glacial border of: true and reworked till deposits, glacial striae, unusually abundant and widespread erratics both near and remote from the glacial border, and unsorted drift occupying places without any regard for topographic position or elevation. Additional evidences of an indirect nature are: the absence of any more conclusive evidence of glaciation immediately north of the old mapped glacial border than south of it and the presence of the Kansas River trough between the erratics and the position which the edge of the melting ice must have had according to the previous mapping.

The line marking the position of the maximum advance of the Kansan ice sheet in northeastern Kansas has been established by investigators at various places[1] and finally located and mapped by Todd[2] as shown on Figure 1. This line separating the glaciated from the unglaciated area in Kansas is essentially the one adopted by the Kansas Geological Survey and published in its most recent map[3] showing the distribution of Quaternary deposits. From studies in the region of the attenuated drift border, the writer has come to the conclusion that an ice sheet extended south of the mapped glacial border. The evidences upon which the foregoing conclusion is based are fourfold: (1) erratics, (2) true till deposits, (3) reworked till deposits, and (4) glacial striae.

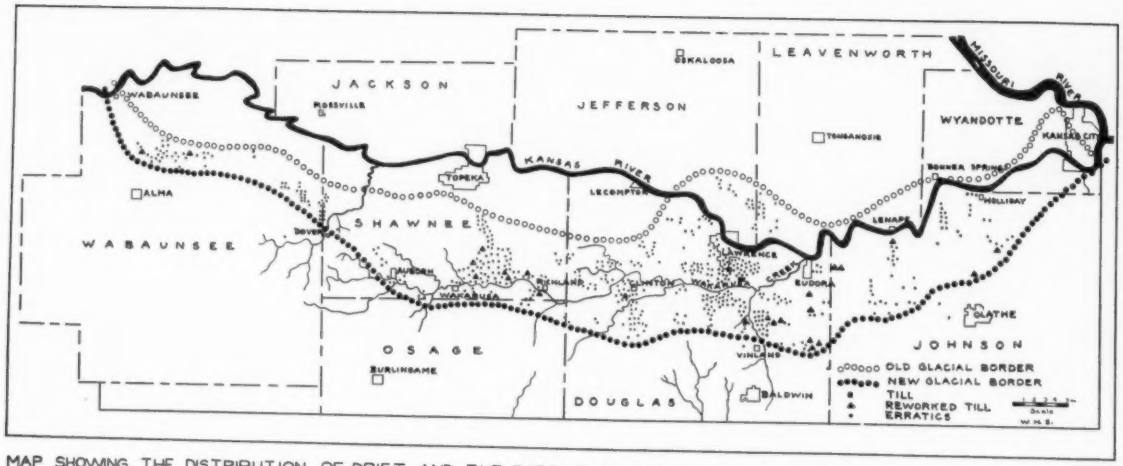
ERRATICS

The presence of some glacial erratics in Wabaunsee, Shawnee, Douglas, and Johnson counties south of the line marking the posi-

[1] R. Hay, "Geological and Topographical Map of Kansas: *Geology and Mineral Resources of Kansas*," *Eighth Biennial Report of the State Board of Agriculture* (1891–92); T. C. Chamberlin and R. D. Salisbury, "Preliminary Paper on the Upper Mississippi Valley, Plate XXI, Diagrammatic Map of Drift Currents Adjacent to the Driftless Area," *U. S. Geol. Survey Sixth Annual Report* (1885).

[2] J. E. Todd, "Kansas During the Ice Age," *Trans. Kansas Acad. Sci.*, XXVIII (1917), 33–47; Plate XI, "Map of Pleistocene Formations of Northeastern Kansas," *Pan-American Geologist*, Vol. XL (1923).

[3] R. C. Moore and K. K. Landes, "Underground Resources of Kansas," *Kansas Geol. Survey, Bull. 13* (1927), Fig. 19.



MAP SHOWING THE DISTRIBUTION OF DRIFT AND THE EXTENT OF THE ICE SHEET SOUTH OF KANSAS RIVER IN KANSAS

FIG. 1

tion of the maximum advance of the Kansan ice sheet has been known for a long time. These deposits have been interpreted as outwash materials some of which were supposed to have been formed while the glacier advanced and others while it retreated.[1] During recent field investigations many new exposures of glacial pebbles and boulders were located and mapped (see Fig. 1). The erratics consist of pebbles and boulders of various kinds and sizes. The following list comprises the most important rock types which are represented: red and white quartzites and quartzite conglomerates, fine and coarse-grained granites, mica and hornblende schists, diorites, gabbros, gneiss, basalt, iron-bearing rocks, chert, quartz, petrified wood, local sandstones, shales, and limestones.

Of the boulders, the pink to red quartzites and quartzite conglomerates are the most conspicuous and numerous and in many places constitute from 75 to 90 per cent of all the boulders present. These erratics are generally very hard, smoothly rounded, and more or less polished. Some, however, are unusually well-weathered, breaking down to sugar-like quartz grains when slight pressure is applied. The granites are represented by two types and next to the quartzites are the most abundant. One of the types is a light-colored medium to fine-grained rock, whereas the other is coarser grained and generally of a reddish color. In size, both the quartzites and the granites vary greatly, ranging from small pebbles to boulders over 9 feet in their longest dimensions (see Fig. 2). Many of the granites crumble to pieces of feldspar and quartz very readily; others are relatively firm. In general, the granites show the effects of weathering much more than do the quartzites.

The darker igneous rocks, such as the gabbros, diorites, and basalts all show characteristic subangular forms and a stage of disintegration and decomposition intermediate between the quartzites and the granites. These rocks as well as the schists and others mentioned in the foregoing are less numerous than the two types first described. The local rocks are not well represented.

A study of the erratics shows at least six facts: (1) The erratics are much more numerous than is indicated in the literature. Erratic boulders have been described as being scattered as far south as

[1] J. E. Todd, "Kansas During the Ice Age," *Trans. Kansas Acad. Sci.*, XXVIII (1917), 39–44.

38 degrees 50 minutes and pebbles to 38[1] degrees N. Lat. It is very doubtful, however, if most of these erratics can be ascribed to the glacial invasion. More likely they were carried eastward by streams coming from the Tertiary sand and gravel plains or else, as intimated by Chamberlin,[2] may be due to glacio-fluvial action. Todd[3] has mapped and described eight localities where erratics occur south of his glacial border. A glance at the map shown on Figure 1 indicates that exposures of erratics are very numerous.

FIG. 2.—Large boulders of granite and quartzite similar to the nine-foot granite boulder shown above occur south of the old glacial border.

(2) Of more importance than the mere number of exposures of glacial drift is the fact that the erratics are very widespread and have a far greater areal distribution than is indicated on the published maps. This wide areal distribution of the northern pebbles and boulders does not harmonize well with the fluvial or glacio-fluvial hypothesis advanced to account for the few and more or less restricted areas of erratics. Undoubted outwash deposits occur in the

[1] B. F. Mudge, *Fourth Agricultural Report and Census, Kansas* (1875), p. 109: T. C. Chamberlin and R. D. Salisbury, "Preliminary Paper on the Driftless Area of the Upper Mississippi Valley," *U.S. Geol. Survey Sixth Annual Report* (1885), p. 314.

[2] T. C. Chamberlin and R. D. Salisbury, *op. cit.*, p. 314.

[3] J. E. Todd, "Glacial Geology of Kansas," unpublished manuscript; Plate XI, "Map of Pleistocene Formations of Northeastern Kansas," *Pan-American Geologist*, Vol. XL (1923).

region under discussion. However, it is not reasonable to suppose that an ice sheet like the Kansan which in Kansas left only more or less patchy and thin deposits without the development of a pronounced terminal moraine[1] should have distributed most of its load by means of streams coming from the melting ice sheet and should have deposited the materials over an area as widespread as that shown on the map (Fig. 1).

(3) The erratics are just as numerous at a distance south of the mapped glacial border as near it. This together with the fact that (4) there is no sorting or separation of large and small materials as they are traced away from the glacial border appears to indicate direct ice action rather than stream deposition. Streams usually sort their materials. Although the sorting may be poor, still some change in the sizes of the pebbles and boulders should be noticeable as they are traced farther and farther away from the glacial border. This, however, is contrary to the facts. Also, not only should there be noticeable differences in the sizes of the materials carried down stream but the boulders and pebbles should become less numerous in the same direction. This also is not evidenced in the field. Almost everywhere in the region immediately north of the glacial border the drift is thin and at many places is patchy and often represented only by scattered boulders. In fact, the country between Topeka and the glacial border west of Lawrence (see map) shows no more conclusive evidence of glaciation than the region south of it. Unless the topography at the time of the ice invasion was entirely different from what it is now, the streams coming from the melting glacier could not have had a high gradient and therefore should have dropped more and larger boulders near the ice edge and carried the smaller ones farther away.

(5) The erratics are not confined to any topographic position; neither are they limited in elevation. Some are found in the valleys, others on the slopes, and still others on the uplands. The previously known drift was mapped as occurring in strips or else confined to definite channels in the region of Wakarusa Valley.[2] As indicated

[1] J. E. Todd, "Kansas During the Ice Age," *Trans. Kansas Acad. Sci.*, Vol. XXVIII (1917), pp. 35, 37.

[2] *Ibid.*, p. 36; Plate XI, "Map of Pleistocene Formations of Northeastern Kansas," *Pan-American Geologist*, Vol. XL (1923).

in the foregoing, the erratics are now known to be widespread, and careful checking of barometric readings made at the exposures show variations of 30, 50, and more than 100 feet within short distances. Streams usually deposit their materials along definite channels and in such a manner that very little difference in elevation exists within short distances. Therefore, the disregard for elevation together with the lack of definite arrangement or distribution of the deposits favors direct deposition by the ice rather than deposition by streams coming from the glacier.

(6) According to the previous mapping[1] the ice sheet crossed the valley of Kansas River about 7 miles northwest of Lawrence. Between that point and Kansas City the valley was unoccupied by ice. It is, therefore, difficult to account for the numerous and widespread erratics south of the river between the two cities mentioned in the foregoing, for between the erratics and the melting ice sheet lay the trough of the river which undoubtedly must have served as the main outlet for the drainage coming from the glacier.

TRUE TILL DEPOSITS

Undoubted evidence of the extension of the ice sheet is established by the finding of true till at two localities. The first of the two exposures is at Haskell Indian Institute located at the south city limits of Lawrence and 11 miles south of Todd's glacial border. The other deposit is $\frac{3}{4}$ mile south and 1 mile east of the Haskell locality in the NW cor., NE $\frac{1}{4}$, Sec. 17, T. 13 S., R. 20 E. Except for the presence of numerous erratics lying scattered over the surface, no indications of an existing till at the two localities were to be seen. In each case the till was discovered through the process of excavating. The Haskell deposit was uncovered at the time of the building of the Haskell stadium while leveling the athletic field by means of the steam shovel, digging trenches for drainage purposes and sites for foundations. At the western end of the athletic field the overburden was removed from an area of about an acre and to a depth of 5 feet. The excavation thus made revealed a true till. A better exposure, however, was brought to light in a trench from 10 to 12 feet deep dug on the south side of the west end of the athletic field. Here, although less of an exposure, the material was to be seen at a

[1] J. E. Todd, *op. cit.*, Map 1; Plate XI.

better advantage because the till was undisturbed. The following materials were exposed:

	Feet	Inches
1. Black loamy soil	2	....
2. Rĕd, sandy, leached till	2	....
3. Band of black silt or soil, containing an occasional quartzitic pebble and grading gradually and irregularly into the till beneath	..	6–12
4. Very red, tough till, thoroughly leached and filled with erratics of various kinds and sizes, exposed to bottom of trench	8	....

The erratics in the tough red till ranged in size from pebbles less than $\frac{1}{4}$ inch to boulders 1 foot in diameter and consisted chiefly of red to pink quartzites with some well-decayed granites and greenstones. There are two tills represented in the foregoing section. The upper till is decidedly different from the lower one in being less clayey, thinner, and containing erratics much smaller in size. The two tills are separated by the black silty band or soil indicated in the section. This deposit is at the edge of the upland overlooking the valley of Wakarusa Creek and is about 50 feet above its flood plain.

The other deposit of till to the southeast of the one just described is essentially similar to the lower 8 feet of the Haskell exposure, excepting that granites and greenstones are more abundant and on the average are larger. This deposit is also on the upland overlooking Wakarusa Valley and is at an elevation of 870 feet above sea-level, or 10 feet lower than the one first described. As in the first case, numerous quartzite boulders dotted the surface without showing any trace of a till beneath. The till was discovered while digging a trench 4 feet deep to the top of the Weston sandstone.

Although only two localities of true till have thus far been located, other deposits undoubtedly exist hidden, as those just described, and only through the building of new roads, excavations for foundation sites, and drainage ditches will they eventually come to light.

REWORKED TILL DEPOSITS

Although true till deposits are scarce, deposits of till partially reworked by rain, gravity, and other agents are fairly numerous and widely scattered (see Fig. 1). It was the finding of these till-like deposits that first aroused the writer's interest and attention to the

possible extension of the ice sheet in Kansas. The material at the till-like outcrops is exposed in road cuts from 100 to 200 feet long and generally about 3 feet deep. In all cases the drift is composed of a brown to red, more-or-less sandy, often sticky, clayey material, thoroughly leached, and containing numerous pebbles and boulders. The coarse materials consist chiefly of red quartzite, well-decayed granites, brown to white cherts, some of which crumble to a fine white powder on even the slightest pressure, gneisses, schists, and sandstones. In size the pebbles average less than $\frac{1}{2}$ inch in diameter. The larger boulders measure from 1 to 2 feet in diameter and consist for the most part of red Sioux quartzites. A loesslike silt covers the deposits in most places. The deposits just described are without question tills which subsequently have been reworked. This is evidenced by the partial rearrangement of the materials into irregular layers of pebbles and boulders following the contour of the topography. The materials show no true stratification. The position of the deposits on the uplands and divides also precludes any other origin but direct glacial deposition.

GLACIAL STRIAE

A fourth evidence of the greater extent of the ice is indicated by the presence of glacial striae several miles east of Eudora and located south of the mapped glacial border. These striae were not observed by the writer but were first reported to him by Dr. W. H. Twenhofel, of the University of Wisconsin, who had seen them a number of years ago.

SUMMARY AND CONCLUSION

To sum up the evidence cited of the tills, both the true and the reworked deposits, the erratics near and remote from the mapped glacial border, their widespread distribution, their lack of sorting, their disregard for elevation, and their presence on the hill tops as well as in the valleys, the presence of the Kansas River trough between the ice edge and the erratics south of the river, the glacial striae beyond the limits of the old glacial border, and the presence of as much conclusive evidence of glaciation south of the present border as immediately north of it, the writer is convinced that an ice sheet extended beyond the limits of the mapped glacial border and reached as far south as is indicated on the accompanying map (Fig. 1).

A SCHIST GRANITE TRANSITION ZONE IN ONTARIO[1]

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ABSTRACT

A belt of old schists is separated from the granite that intrudes it by a transition zone, which consists of foliated rocks formed by the metasomatism of the schist. Some porphyritic rocks have been developed. There is no evidence that the rocks of the transition zone were fused or that they were in the state of a "crystal mush."

INTRODUCTION

Papers[2] in recent numbers of this journal have described "a syntectic porphyry" and "a reaction porphyry" formed in schists near plutonic rocks of intermediate basicity. It is the purpose of the present paper to describe a transition zone, which includes a porphyry, found at the contact of schists and granite. In the locality here described the transition phenomena are extensive, both in areal distribution and the amount of change. Numerous exposures are available giving a favorable opportunity for study. The area includes the northern parts of the townships of Hess, Moncrieff, and Craig and the southern parts of the townships of Munster, Ulster, and Stralak. It is about 40 miles west of Sudbury on the main line of the Canadian Pacific Railway.

A band of basic gneisses and schists over 20 miles long and about 2 miles wide has been intruded by granite (see Fig. 1). The schists have a nearly vertical foliation striking east and west, except for minor flexures. In the course of areal geological mapping it was found impossible, especially on the north side, to draw a boundary between much of this rock and the granite that intrudes it. The contact is a transition zone from a few hundred feet to over a mile wide. The southern boundary of the schists is covered by infolded and infaulted Huronian rocks or by drift.

The normal granite is characterized by pink feldspar, lack of

[1] Published with the permission of Thomas W. Gibson, Esq., Deputy Minister of Mines for Ontario.

[2] A. R. Whitman, "A Syntectic Porphyry at Porcupine," *Jour. of Geol.*, Vol. XXXV (1927), pp. 404–20. G. E. Goodspeed, "The Mode of Origin of a Reaction Porphyry Dike at Cornucopia, Oregon," *Jour. of Geol.*, Vol. XXXVII (1929), pp. 158–76.

structure, and low content of mafic minerals. Passing from the normal granite toward the schists a foliation shown by an alignment of the dark minerals appears. The dark minerals increase in amount and the foliation parallel to that of the schists becomes more apparent. The rock becomes somewhat finer in grain and grades into a rock with a gneissic structure but showing subhedral phenocrysts of pink feldspar and megascopically visible crystals of titanite. Closer to the schists the phenocrysts are not prominent but much pink feldspar has been introduced. At the inner margin of the transition zone the gneisses with the pink feldspar give way to the dark gneisses and schists. Other sections across the transition zone show similar features. Widths of the different transition types may

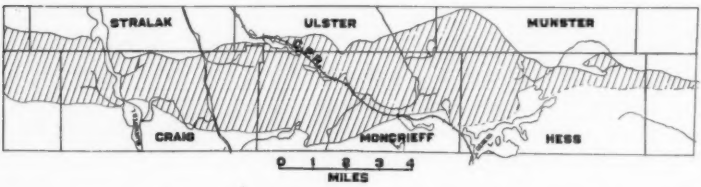

FIG. 1.—Belt of schists included within granite. Part of the southern boundary is reconstructed beneath the mantle of Huronian rocks and glacial drift.

vary or some may be lacking altogether, but the increase in the foliation with the increase of the dark minerals and retention of the old schist structure are constant features. Similar transition zones have been described by Collins[1] in the Onaping Map-area to the north of the one here described.

Natural exposures of a part of the transition zone are supplemented by surface development work and the cores from an extensive diamond drilling campaign at the Geneva Lake Mines. The writer was able to study this very excellent material through the courtesy of Mr. W. E. Bawden, superintendent for the company. The rocks are those that characterize the schist side of the transition zone, and therefore show much dark mineral, and the foliation is marked. They are cut by granite, pegmatite, and aplite dikes, which are probably satellites of the batholith.

[1] W. H. Collins, "Onaping Map-area," *Geol. Surv. Can.*, Mem 95, 1917.

An exposure a few feet north of the tank supplying oil to the air compressor is especially instructive in considering the mode of origin of the rocks of this zone. The exposure is nearly vertical and is slightly inclined to the direction of strike of the foliation; therefore the foliation appears as nearly horizontal lines. The rocks have been rendered somewhat gneissic by the introduction of pink feldspar. What appears on first sight to be a porphyritic dike cuts irregularly across the foliation and extends a short distance parallel to it. Where the boundary is parallel to the foliation it is gradational, but where it cuts across, it is abrupt and marked by a zone rich in feldspar. The foliation of the surrounding rocks may be traced across the dike-like gneiss body. Furthermore, bands in the schist particularly rich in mafic minerals may be traced across the "dike" as darker zones. Examination of the field occurrence and a number of polished surfaces of the rocks shows the feldspar was first introduced parallel to the foliation and the pseudo-phenocrysts are of later development. The feldspar was formed at the expense of the dark minerals. Furthermore no movement took place during the formation of the gneiss, therefore, the process must have been one of replacement.

PETROGRAPHY OF THE SCHISTS

The band of old rocks is narrow and the original structures have been obliterated by metamorphism. It is presumed that they are of Keewatin age, but none of the characteristic structures may be seen. The steep foliation is the most constant feature. In a few places within the belt chloritic schists may be found, but hornblende schists preponderate. This rock may be taken as the one from which the transition zone was formed. The predominant constituent is amphibole with subordinate gray feldspar, which is seen under the microscope to be of the composition of andesine.

PETROGRAPHY OF THE GRANITE

Away from the belt of schists the granite is of surprising uniformity in petrographical character. Exposures along the railroad show that there is not much variation in the rock from a point 5 miles south of the schists to one 15 miles north. Furthermore the granite is very similar to one described by Collins[1] in the Onaping

[1] W. H. Collins, *op. cit.*

Map-area. The appearance of the hand specimens varies due to the different proportions of the minerals present or to differences in granularity, but the microscope shows that the kinds and relationships of the minerals are essentially constant. The principal mineral is a pink feldspar, which may appear as phenocrysts. Quartz is present in moderate amounts. The mafic minerals form such a small part of the rock it may be called an alaskite.

Microscopic examination shows that the sodic plagioclase exceeds the microcline. The microcline is clear and almost invariably twinned. A sodic oligoclase is found in many of the thin sections. Albite is less prevalent, and in only one thin section was plagioclase as calcic as Ab 70 An 30 found. A zoning showing a range of more than four mol per cent anorthite is rather exceptional.

The plagioclase is clouded with alteration products except for an occasional clear rim. The alteration products are white mica and epidote. Many of the mica plates are parallel to the base and side pinacoid of the feldspar, but a few are in random orientation. The plagioclase is subhedral, and the microcline and quartz are molded against it. The quartz shows some fractures and strain extinction. The mafic minerals are commonly altered to dark green chlorite. Hornblende or biotite were found in only one or two sections out of a dozen taken from various places in the granite area. Apatite, titanite, and opaques in idiomorphic grains are accessory minerals. The sphene produces some pleochroic haloes in biotite.

The uniformity of the granite over a wide area suggests that it may represent the unmodified batholithic rock, furthermore Collins[1] comes to the same conclusion regarding a very similar rock in the Onaping Map-area.

PETROGRAPHY OF THE TRANSITION ZONE

Sixteen thin sections of the rocks of the transition zone were available for study. Unfortunately even this number is not sufficient to give a complete outline of the processes which went on in this zone; however, enough information is available to give a general outline. The schist with amphibole and an intermediate plagioclase may be taken as a starting-point. The plagioclase is zoned,

[1] W. H. Collins, *op. cit.*, p. 53.

and some individuals are clouded with sericite and epidote, others are clear and untwinned. Amphiboles are the prominent mafic minerals. Hornblende predominates, but actinolite and tremolite are present in noticeable amounts. Epidote and biotite are present in small amounts. Titanite, apatite, pyrite, and magnetite form small irregular grains.

On further modification the rock shows a decrease in actinolite, tremolite, epidote, and biotite and an increase in the sodic and potassic feldspar. The feldspars form ovoid aggregates, which may contain oriented fragments of amphibole. At a still later stage the actinolite, tremolite, epidote, and biotite vanish, and the mafic mineral is hornblende. It is optically negative, 2V about 65°, $Z \wedge c$ 21°, indices of refraction between 1.63 and 1.66, X-yellow, Y-olive green, Z-blue green, dispersion $p > y$. The properties agree with those of hornblende except the dispersion. The accessory minerals, apatite, titanite, pyrite, magnetite, are prominent and euhedral. A bromoform separation of the material between 40 and 240 mesh shows only hornblende and the above-mentioned accessory minerals.

CONCLUSIONS

The products formed by the action of granite on schists have been discussed by many authors. It is not proposed to enter upon a long discussion of the manner of formation of the transition zone, but to give the principal conclusions possible from the field relationships. There is no evidence that pegmatitic material was injected parallel to the foliation of the schist; even some of the finer-grained pegmatite dikes show residuals of dark minerals arranged in a manner that strongly suggests they were formed by replacement. The way in which the direction of foliation of the rocks of the transition zone faithfully follows that of the schists, is evidence that the rocks were never molten nor a "crystal mush."

If the material had been molten or partially so it might be expected to show the intricate crenulation characteristic of the migmatites. The writer failed to find any crenulations which could not be explained as belonging to the original schists. The process then must have been one of metsomatism, and this is supported by the relationships of the dike-like mass at the Geneva Lake Mines. The

basic schists were replaced and altered by solutions, which introduced quartz and feldspar and formed the characteristic hornblende of the rocks of the transition zone. The rocks on the granite side of the transition zone were modified to such an extent that they are indistinguishable from the granite. On the schist side the rocks are only the slightly modified gneisses. The intermediate zone is characterized by the development of the porphyry, which was never molten.

The time relationship between the formation of the transition zone and the period of consolidation of the granite is a problem of considerable interest. Was the transition zone formed before the consolidation of the granite or after? At a locality north of the middle part of the belt of schists, rocks of the transition zone are involved in an igneous breccia. The matrix resembles the normal granite very much, and is believed to be part of it. Many of the fragments of the rock included show the steeply dipping foliation parallel to that of the schists, although many have been rotated. The granite of the matrix shows a fluidal arrangement of the dimensioned crystals about the blocks. If the same relationship holds for all parts of the transition zone, then it was formed before the consolidation of the granite. Removal of part of the transition zone by stoping or otherwise may account for the absence or narrowness of the transition zone in some places.

ACKNOWLEDGMENTS

The writer wishes to acknowledge his indebtedness to his colleague, Dr. J. J. Runner, for discussion of phases of this problem.

SEDIMENTATION IN A GLACIAL LAKE[1]

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ABSTRACT

The description of the sediments includes chemical analysis, figures showing the size of the particles of sediment in different parts of the lake, the rate of clearing of the water under laboratory conditions, and the character of the lamine which are being formed.

Lake Cavell is a glacier-fed lake located in the Rocky Mountains in the western part of Jasper Park about $\frac{1}{3}$ mile below Edith Cavell Glacier, at an elevation of 5,610 feet. It has a length of $\frac{5}{8}$ mile with an average width of about $\frac{1}{8}$ mile and a maximum depth of 37 feet. The upper end of Lake Cavell has been filled for about $\frac{1}{2}$ mile by sand and gravel from the subglacial stream (Fig. 1). The surface of this delta plain is covered by an alpine flora in which the cotton-tipped stems of cotton grass are dominant.

SCOPE OF INVESTIGATION

A study of Lake Cavell made in 1927 included the taking of temperature records at different depths, the collection of bottom samples, analysis of the sediment entering the lake, a series of soundings, observations with reference to macroscopic forms of life, and observations on the rate of settling of the sediment from the subglacial stream entering the lake. The last-named observations were in progress for five months. Mr. E. J. Fraser has kindly co-operated with the writer by supplying data on the size of the particles comprising the sediments.

In sharp contrast with all other lakes not expansions of rivers, which were studied at lower levels, this lake was found to be without thermal stratification, the bottom and upper levels having essentially the same temperature. The nearly continuous accession of water from the glacier and the cool nights afford an explanation of the absence of thermal stratification. The absence from the shallow part of the lake of all of the water plants observed in lakes a few miles away at levels some 2,000 feet lower must be attributed

[1] Published with the permission of the Director, Geological Survey of Canada, Ottawa.

to the cold water and absence of thermal stratification. The entire absence of marl or calcareous sediments from the deposits of the

FIG. 1.—Lake Cavell and rock-covered glacier in the foreground. The black line marks the margin of the glacier. The flat delta plain is seen between the head of the lake and the dense forest. (Picture by Dr. McKay.)

lake is correlated with the absence of water stratification as well as with the absence of $CaCO_3$ from the water entering the lake.

ANALYSIS OF SEDIMENTS

The chemical constituents supplied to the lake by the subglacial stream are indicated by the analysis of sediments contained in a jar of water collected by the writer from the stream about 250 yards below the glacier. This includes the analysis of water decanted from the sediment after settling of the rock-flour, an analysis of the

material in colloidal suspension and one of the sediment. These are given below:

Constituents*	Parts per Million
Sulphuric acid (SO_4)	None
Bicarbonic acid (HCO_3)	Trace
Carbonic acid (CO_2)	22
Chlorine (Cl)	Trace
Silica (SiO_2)	Trace
Ferric oxide and alumina (Fe_2O_3), (Al_2O_3)	Trace
Calcium (Ca)	None
Magnesium (Mg)	Trace
Sodium (Na)	None
Potassium (K)	Trace
Total suspended material: rock-flour, fine sand, etc., dried at 105° C.	2,880 P.P.M.
Equivalent in one imperial gallon to	201.6 gr.

Includes:	Parts per Million
SiO_2 in colloidal suspension	10
Al_2O_3 in colloidal suspension	9
Fe_2O_3 in colloidal suspension	21

Composition of suspended material:	Per Cent
SiO_2	90.00
Al_2O_3	3.49
Fe_2O_3	1.31
CaO	0.0
MgO	.64
Na_2O	0.68
K_2O	3.37
Ignition loss	.61
	100.10

*Analysis by A. E. Thompson, Mines Branch.

The gathering ground of the glacier is a mountain slope consisting of heavy bedded quartzites, which accounts for the absence of $CaCO_3$ from the water of the stream. The Al_2O_3 and K_2O of the analysis are probably derived from occasional pebbles in the quartzites.

SETTLING OF SEDIMENT

When examined the lake water had a straw-yellow color over the delta for a distance of 60 feet from the mouth of the main out-

let of the glacial stream. A sharp line separated the area of straw-colored-sediment-loaded water from the pea-green lake water just outside this line with less coarse sediment and with a density sufficiently different to keep the recently introduced glacial water segregated from the main body of lake water. This temporary density segregation over the delta area where the water was from $\frac{1}{2}$ to $4\frac{1}{2}$ feet deep contributes toward concentrating the maximum deposition of suspended sediments over the delta.

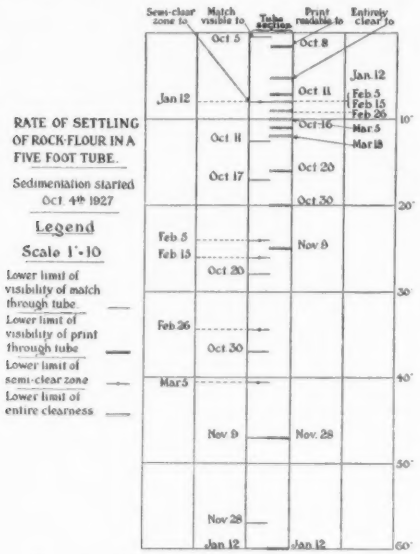

FIG. 2.—Glass-tube section showing settling record for rock-flour.

A second jar of water collected from the glacial stream entering the lake at the same time and place as that represented by the analysis was taken to Ottawa. This water, after agitation to put in suspension the part of the rock-flour which settled in transit, was placed in a 5-foot glass tube 2 inches in diameter which was kept at a temperature a few degrees above freezing. Observations extending over a period of 165 days were made on the rate at which the sediment in this tube settled. The results of these observations are recorded in Figure 2. Inspection of this graphic record shows that the finer material descends very slowly. The water in the tube was so murky twenty-four hours after settling began that a matchstick was visible through it only $\frac{1}{2}$ inch below the top. The record shows that the bottom of this match-visibility zone dropped at a rate of less than $\frac{1}{2}$ inch per day. After standing twenty-five days clearing had proceeded sufficiently to permit the reading of ordinary newsprint only through the upper 20 inches of the tube. After seventy-eight days the semiclear zone had dropped only 48 inches,

and after five months the zone of entire clearness had dropped only 10 inches. It is apparent from these observations that the water in the deepest part of the lake, which has a depth of 37 feet, would, if no fresh sediment were introduced for one year, still retain enough sediment in suspension near the bottom to render it very murky. Since complete clearing of the water proceeded at the extremely slow rate of a small fraction of an inch per day, it is evident that lake deposition continues in winter, but at a very slow rate and with the deposition of very fine material.

These observations indicate that deposition, even in a glacial lake which receives little or no water during the winter, does not cease when the accession of sediment to the water of the lake stops. Deposition of very fine sediment continues throughout the winter from the summer supply brought into the lake during the active period of the subglacial stream. We have, therefore, a summer period when both very fine and relatively coarse sediments are being deposited alternating with a cold-season period when only very fine sediments are laid down. This alternation of the deposition of colloidal and other fine sediments with layers composed largely of the coarser elements of rock-flour should give a pair of laminae differing slightly in color and texture and representing a time interval of one year. There is, however, a possibility that the interruption of warm summer weather by temporary cold periods and the consequent great fluctuations of the volume of the subglacial stream may complicate the problem of translating the record into years.

SIZE OF PARTICLES

Mr. F. J. Fraser has kindly furnished the following information concerning the size of the particles present in the lake-bottom sediment, the water of the subglacial stream which enters the lake, and in the water of the lake itself.

Sediment from the lake bottom near the middle (No. 2) and from the lake bottom near the lower end (No. 3) shows the contrasts indicated. Maximum size of grains is of the order indicated below:

No. 2..... 0.04 mm. No. 3..... 0.02 mm.

Amount of sediment, greater than 0.01-mm. grade, by elutriation:

No. 2..... 25 per cent No. 3..... 10 per cent

Number 3 sample is definitely finer than No. 2.

In both samples diatoms up to 0.1 mm. in length are plentiful in the large grades separated.

Of interest are the "twisted" forms of diatoms. Number 3 sediment contains in the "flocculent" material dark, shiny hemispherical diatom "valves."

Samples 2 and 3 are from stations about $\frac{1}{4}$ mile apart; hence, the figures show that most of the quartz particles with a diameter between 0.04 and 0.02 mm. reach bottom during the movement of the sediment-laden water across the lower $\frac{1}{4}$ mile of the lake.

Microscopic examination was made of the sediment in the stream from Cavell Glacier, in the water over the delta of the lake (No. 5), and the water near the lake outlet (No. 4) nearly a mile from the delta. The maximum size of grains is of the order indicated below:

Sediment from glacial stream shows a maximum diameter of 0.3 mm. and a minimum diameter of 0.02 mm. About 50 per cent of this sediment is made up of the larger grains; the remainder average 0.1 mm. diameter. The particles from No. 5, the delta end of lake, are 0.1 mm., and from No. 4, the lower end of lake, 0.01 mm. in maximum diameter. The sediment in the stream near the glacier, in the upper and lower ends of the lake, thus shows maximum sizes of 0.3, 0.1, and 0.01 mm.

From a column of water in a 2-inch tube left standing five days samples were taken 6 inches below the top; the grains in suspension were found too small to be measured directly. Examination with a $\frac{1}{2}$-inch oil-immersion lense suggests a probable diameter of the grains to be of the order of 0.0005 mm., certainly much less than 0.0015 mm. The extremely small size of the particles which remain in suspension for many days may be inferred from this.

BANDING OF SEDIMENTS

The general appearance of the banding of the Lake Cavell bottom sediments is shown by the photographs of the sediments made after drying. The slight divergence of the bands from horizontal is the result of slight deformation produced in the course of removal from the sampler.

The banded sediments in Lake Cavell are much lighter colored than any recent lacustrine deposits which have come under the

writer's observation This is doubtless the result of their highly siliceous character. In their light color they approach the St. Eugene silts of the Columbia River valley which are lacustrine deposits of Tertiary age. The lake-bottom sediment shows alternating light- and darker-colored bands, the former 4–5 mm. and the latter about ½ mm. in thickness. The wide bands are in some cases marked

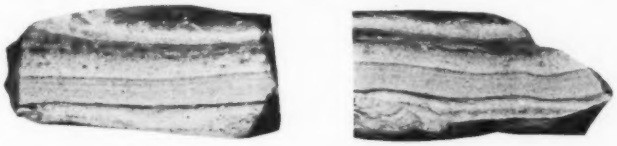

FIG. 3.—Laminated sediment from the bottom of Lake Cavell

by indistinct bands without well-defined color contrasts, ½ mm. or less in thickness. The wide, orange-gray bands approximate closely to 21 E. 3 of the Goldman-Merwin color chart, while the thin bands fall in the gray 21 E. 4 of this chart. The thin gray band is interpreted as the winter deposit and the light-orange band is considered the summer deposit, while the indistinct thin bands within the latter are probably produced by low summer-temperature periods checking the access of sediments to the lake.

SPRING PITS; SEDIMENTATION PHENOMENA

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ABSTRACT

Pits were developed in a sandy beach by springs. The pits contain the coarser sediment in the middle and the finer about the edges, an arrangement of sediments contrary to that common in basins of deposition.

Unusual geological features were found last summer near Parry Sound, Ontario, which the writer proposes to call "spring pits." They were found on the south shores of Maple Lake, situated in the district of Parry Sound, the township of Christie, about 12 miles east of the city of Parry Sound, and near the village of Orrville.

About the shores of the lake there is a rather extensive, massive diorite which forms a nearly impenetrable watershed from which the run-off streamed copiously during the heavy rains of the season of 1928. At the shore in one place there is a low cliff of diorite separated from the water's edge by a sandy beach. The cliff is at the head of a little bay, flanked by rocky shores on either side, and sheltered from wave action not only by its position, but also by the sandy-shore deposits which have naturally accumulated in the quiet waters of the cove (Fig. 1).

Ordinarily a little creek which enters the lake at the head of the bay carries off the larger part of the run-off from the neighboring surface, but during excessive rainfall the water streams over the edge of the cliff and pours in a sheet toward the lake below, passing in its course over or through the sandy beach. At such times the sandy deposit is saturated with water, and the run-off in part ponds behind the low beach, whereas the surplus runs across the beach cutting a channel to the lake and finally drains the pond. During the summer of 1928 there were periods of excessive rainfall at a time when the level of the lake was so high that part of the beach usually out of water was submerged. The sand was exposed at the foot of the cliff for a width of about 30 feet, with a slope toward the lake of perhaps 3 feet in that distance. The water poured into the sand at

the foot of the cliff so fast that it worked its way beneath the surface and came out under water beyond and at the edge of the beach in a series of springs. Many of these springs were in action at the same time, separated from one another by the distance of from less than 1 to 3 feet. Such was the rush of water from below that each outlet made for itself a crater or bowl-shaped depression by the erosion and transportation of the upwelling streams. After the storms were over and the level of the water subsided, the strange series of pits

FIG. 1.—Massive diorite watershed behind a sandy beach on the south shore of Maple Lake, Christie Township, Parry Sound District, Ontario.

made by these springs became exposed to view. When the writer first saw these depressions as he passed in a canoe he supposed them to have been formed by the feet of wild animals. However, they were unusually large and irregularly spaced, and closer inspection showed that they were quite out of the ordinary (Fig. 2).

One of the peculiar features, and the one which gave the clue to their origin, was the presence in certain of the pits of a little drainage channel leading from the bottom of the pit toward the lake. Other curious features were recognized later. For instance, the size of grain of the sand making up the bottom and walls of the pits varied from a maximum in the middle and at the deepest part of the pits to a minimum at the outside and at the top of the walls of the pits. This

is exactly opposite from the distribution of sand grains according to size in a basin of deposition, and is in itself a proof that the depressions are actually pits of erosion. Many of the pits were formed under water, a fact indicated by the absence of any channel leading away from certain of the pits. After the lake lowered from its unusual height, these pits were not exposed until they were no longer running as springs but while they were still full of water. As the level of the lake sank, the water drained out of these pits, not by overflow but by seepage, into the sand below. In spite of the fact that this

FIG. 2.—A group of spring pits on the sandy beach shown in Figure 1. Most of these pits are about a foot in diameter and up to 6 inches deep.

change in water-level was so gradual that there was no corresponding erosion or transportation of sand, nevertheless the sides of the pits were so steep that leaves and little sticks floating on the water settled without grounding or coming to rest on the sides until the last of the water drained away, when this flotsam concentrated on the bottoms of the pits. Here then we have evidence that the water rose with sufficient force to sweep out the fine grains of sand, leaving only coarse grains in the center, and to pile up the material in a ring about the edge, and then that water sank back again so gently that nothing was eroded, although floating objects sank to rest upon the bottom as soon as the depression was drained (Fig. 3).

Features of this type doubtless have formed at other times and in other places, but so far as the writer is aware they have not hitherto been described and explained, and yet they belong properly with the shore-line features of the class of mudcracks, raindrop impressions, rill marks, pollywog pits, salt crystals, clam and sea-bird tracks, and other minor geological phenomena which become only occasionally of importance and then usually only significant when found in association one with another. Spring pits with outlet channels have been formed and have functioned when the top of the spring pit was above the level of the neighboring standing water, and those which have no drainage channels were formed under water, and ceased to flow appreciably after they were uncovered by the sinking of the neighboring water-level. These pits or craters are usually less than 2 feet in diameter, their walls are about 2 inches above the level of the surrounding sand, and probably 4 inches below, having a total depth of 6 inches. They were characterized by a gradation of size of grain from a maximum coarseness in the central deep part to a minimum at the outside edge.

FIG. 3.—Spring pits. The knife rests upon the dividing wall between contiguous pits. The sand grains in the bottom of the pits are coarse; those left on the sides and swept over the edges are fine. Small sticks and leaves which once floated on the water in these depressions now rest on the bowls seeped away through the sand.

If features of this type were to be seen in the sandstones of the Paleozoic formations, would their true nature and origin be recognized by the geologist concerned, and would their significance as indicating strand-line deposition be appreciated?

REVIEWS

Geologie und Radioaktivität. By GERHARD KIRSCH. Vienna and Berlin: Press of Julius Springer, 1928. Pp. 214; figs. 48. $4.35.

This book is one which should be in every university library and is one in which chemists, physicists, and geologists alike will find matter of interest. To be sure, the first twenty-eight pages give a short general discussion of radio-activity which can be found in English in Lawson's translation of Hevesy und Paneth. The next section of the book, on the distribution of radio-active substances, is more or less covered by information in the first part of the *International Critical Tables*. Nevertheless, there is new material, and the material is arranged so that it gives more suggestion for thought. The next section, on the radio-active materials as sources of energy, discusses their effect upon the cooling of the planet and has a discussion of the controversy between Jeffreys, Joly, and Holmes. One can refer to the various papers in the English journals, but even then one would find this critical condensation of the arguments of distinct value; and there are numerous little tables showing the amount of radio-activity and of the radio-active substances in the various layers of the earth. To be sure, some of the statements may need slight revision in view of the work upon which Pigott is engaged; but to almost all, the tables of the mineralogical contents and radio-activity of various granites will be welcome. The discussion of the matter is brought up to date with references as late as 1927 and 1928.

It should, however, be emphasized that the theory of discharge of energy by magmatic cycles is, as he emphasizes, still quite uncertain; and when he assumes, as he does in a later part of his work, that the broeggerite of the Swedish pegmatites has occurred at seven different times, each marking a period of reheating and separated by something like thirty-five million years, while the application is interesting, we must realize that the length and number of these cycles is entirely different as conceived by Joly and by Holmes, and that Holmes, as he writes the reviewer in a private letter, is by no means sure of the cycles yet. Nevertheless, it is a great gain to be reminded not to assume a particular age for all the minerals of a pegmatite too easily.

In this part of the work we have an up-to-date consideration of the layer of Sial which underlies the ocean and the continents. After the ac-

count of the writings of others, he proceeds to give from pages 111–122 a treatment of his own with a number of original suggestions, concluding that the

> theory of magmatic cycles furnishes a number of more or less necessary consequences which we may hope to compare with experience, so that we may hope that in coming years it will be fruitful both for geophysicists and geologists, although it still has so great elasticity on the physical side that it may well be treated with mistrust. At present, the geologic data and those of gravity and seismology [and the reviewer may add "geothermal gradients"] are hardly accurate enough to bear any great burden of theory which has but one interpretation, or is strictly mathematical.

The third section discusses radio-activity as a self-registering clock, mainly by the lead method. Here he differs materially from previous authors in using a value of the thorium to convert its lead-producing power into that of uranium, which is very widely different from that of previous authors, 0.25 instead of 0.38. This is not the mere effect of the slight inaccuracy of the statement when he says that k (p. 131) is the ratio between the rate of disintegration of thorium and uranium. This is not strictly true, for it is the lead-producing power which is concerned, and the atomic weights come into question. In discussing the method of getting the constants, he thinks that the best method is based upon an analysis of a thorianite whose atomic weight happened to be exactly that of the lead, so that without being much troubled with the percentage of lead therein contained, we could, from the percentage of uranium and thorium and lead and the atomic weight given, infer the relative lead-producing power. It is, however, doubtful whether we can really lay as much stress upon this one analysis as he has done, and Dr. Kovarik will probably soon review the whole matter.

The author's discussion of the material for age determination includes a mass of original material, including something like sixty analyses of the Swedish broeggerite, and whatever views one may have, this material cannot be overlooked. In this matter he takes a conservative position and especially calls attention to the fact that atomic-weight determinations and analyses should for certainty be based on the very same crystal, and that metamixed minerals cannot be safely trusted. Even if for such minerals as uraninite the age of the crystals may be obtained with reasonable assurance, the dating of formations and of disturbances is quite another matter, which he says is possible only on a thorough investigation of the occurrence based on a whole series of analyses. This may be putting it rather too strongly, for in any particular case the direction of the possible

error can often be indicated, and other geological arguments may come in to limit the possibilities. Nevertheless, it is well to have in mind.

There are appendixes on the helium method; and the importance of potassium and beryllium are mentioned, and the possibility of the importance of gallium. There is also an appendix upon the pleochroic halos, with regard to which it is a pity that the work of Kerr-Lawson was not mentioned. This is perhaps the only important oversight in a very helpful bibliography which closes the book.

It should be emphasized that there is a great deal of new unpublished material. For instance, on page 46 we have some investigations by H. Pettersson of the deep-sea deposits; and we have a number of analyses, by Ulrich and others besides the author, which here find their first publication. Not only that, but the discussion of the recoil activity of disintegrating atoms as well as the proper disintegration constants are new contributions to the subject, as well as his criticisms of estimates of age based on percentage of equilibrium. The author is a leader in research; and though the book has a general appeal, not an appeal merely to the specialist, it contains material which will be a part of the progress of research in this direction.

ALFRED C. LANE

The Stratigraphy of the Pennsylvanian System in Nebraska. By G. E. CONDRA. Nebraska Geological Survey, *Bull.* 1 (2d ser.), 1927. Pp. 291, pls. 7.

The collection of facts into one book and the completing of work on a stratigraphic unit are always of great aid to a stratigrapher. This *Bulletin* is a complete summary of earlier researches and of more extensive detailed work of the Nebraska Geological Survey on the stratigraphy of the Pennsylvanian of Nebraska.

The Des Moines series is not exposed in Nebraska, but its presence is shown in well logs. A nearly complete section of the Missouri series has been pieced together from outcrops which are scattered through southeastern Nebraska. The formations and their members have been correlated with those of Kansas, Iowa, and Missouri, and the names used there have been applied to their correlatives in Nebraska. The lithologic divisions of the members are only of local continuity, and have been given new names where they occur in Nebraska.

Maps and structure sections show the distribution of the various formations, and lithologic sections have been taken in all parts of the outcrop area. Correlations with the formations of Oklahoma and of Texas are given in the closing chapter.

C. C. B.

The Occurrence and Correlation of a Devonian Fauna from Peace River, Alberta. By EDWARD M. KINDLE, Chief of the Division of Paleontology of the Canadian Geological Survey. *Canada Department of Mines, Geological Survey Bull. 49*, 1928, pp. 14–18.

Bulletin 49 is a continuation of the well-known "Contributions to Canadian Paleontology," and is a worthy addition to the long series of paleontological papers which have been published from time to time by the Canadian Survey. Besides Dr. Kindle's paper, the *Bulletin* contains papers by Wetmore, Bather, Foerste, McLean, and W. A. Bell.

Dr. Kindle's paper lists a fauna collected along the lower Peace River at Peace point, above the gypsum cliffs in both banks of the river. The gypsum cliffs are Silurian, and consist of gypsum, anhydrite, and magnesian limestone. They extend along the river for about 12 miles, rising from 20 to 80 feet above the water. The rocks exhibit low folds, thought to be due to the pressure incident to the hydration of anhydrite into gypsum. These stresses have also produced some remarkable breccias. The fauna of the gypsum beds indicates late Silurian, probably Bertie or Akron.

The Devonian overlies the Silurian with angular unconformity. Ancient caverns or solution chimneys in the Silurian are filled with Devonian clay. The fauna of eighteen species indicates about lower Portage or Ithaca age. Judging from the photograph reproduced on Plate III, some of the rock must be very fossiliferous.

To have these faraway formations of boreal North America described and correlated is a very distinct service to geology. The field work is attended with no mean difficulties; and Dr. Kindle and his colleagues of the Canadian Survey are to be congratulated on the increasingly successful results of their efforts to fit this distant region into its proper place in the synthesis of American geology.

E. R. CUMINGS

STORROW FELLOWSHIPS IN GEOLOGY AND GEOGRAPHY

In view of the remarkable scarcity of fellowships in geology and geography as compared with other physical and chemical sciences, those interested in the former subjects will welcome the announcement by the chairman, Dr. Arthur Keith, of the Division of Geology and Geography in the National Research Council, that through the generosity of Mrs. J. J. Storrow, of Boston, several liberally planned fellowships in geology and geography will be granted under that Division of the Council. The only condition imposed by the donor is the desirable provision that she will have opportunity to establish personal acquaintance with the fellows.

The purpose of the fellowships is to enable young men of unusual ability and aptitude for the work to embark in the field of research in any branch of geology or geography. They are without restriction as to institution, though the Committee may designate the institution to which a given fellow shall go for given work. No advanced degree will be required, though it is presumed that the candidate will have had training equivalent, at least, to the Bachelor's degree. Further, the fellow need not be a candidate for an advanced degree, the view of the Committee being that training for research and the launching of gifted young men in successful research are more important than the routine attainment of a degree. The Committee desires especially to aid several men of outstanding qualities who lack funds for the final training needed to carry them over under the best guidance into well-founded research careers. The awards will not be confined to students but may go to the young man out of college who, by means of a fellowship, may be enabled either to enter on a research career for which his preparation is already nearly complete or to secure further training in a line of research which he has already entered with evident promise of making good.

The annual stipend is $1,200 or more, depending on the conditions obtaining in the particular case. Commitments will be for one year only.

Applications will be welcomed. Much care will be taken to determine the qualifications and particularly the ability of the candidate to make the best use of the opportunities to be offered. The applicant should state age, training, work done, objectives and plans, giving references. Correspondence should be addressed to Chairman, Committee on Fellowships, Division of Geology and Geography, National Research Council, B and Twenty-first Streets, Washington, D.C., and should be in the hands of the Committee before April 5, 1930.

DAVID WHITE
Chairman of Committee